ESTONIAN UNIVERSITY OF LIFE SCIENCES

Institute of Agricultural and Environmental Sciences

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BIOSEQUESTRATION OF GREENHOUSE GASES IN FOREST ECOSYSTEMS BASED ON DATA OF SMEAR STATION IN JÄRVSELJA

KASVUHOONEGAASIDE BIOSEKVESTRATSIOON METSAÖKOSÜSTEEMIDES JÄRVSELJA SMEAR JAAMA ANDMETE PÕHJAL

Master´s Thesis
Environmental management and policy specialty

Supervisor: Steffen M. Noe, PhD

Tallinn 2021

ABSTRACT

Estonian University of Life Sciences Kreutzwaldi 1, Tartu 51014		**Abstract of Master´s Thesis**	
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IPCC special report ‘Climate Change and Land’ indicates forest ecosystems as one of the most cost-efficient and feasible carbon dioxide biosequestration measure to achieve global warming level under 2°C (IPCC 2018). Aim of this thesis work is to research forest ecosystem’s influence on greenhouse gas concentrations and estimate forest ecosystem’s capacity to biosequestrate (on an examle of forest in Järvselja). This research was made on the base of data from mesuring sites Integrated Carbon Observation System (ICOS), National oceanic and atmospheric administration (NOAA) and SMEAR Järvselja. The data was analysed by data science methodology and instruments – Python programming language, Jypiter environment, Mathlab toolbox and Panda library. The results of work show that forest ecosystems do biosequestrate more greenhouse gases than they emmit overall, however on a yearly perspective it is not always so. There are many factors influencing the greenhouse gas concentration and biosequestration capacity localy, alhough the CO2 concentration is ricing from South pole to Finnish tundra with

nearly the same speed (0.5% - 1% per year). This aspect should be researched further in order to elaborate efficient methods in land use globaly, as it seems that local solutions do not influence the local greenhouse gas concentrations. The compare of gross primary production of forests in Estonia, Finland and Sweden correspond to the previous researches of SMEAR stations and confirm that it falls from south latitudes to the north ones.

That may indicate a possible increase of gross primary production due to global climate warming.

Results of this work also incourage to use more widely data science methods for environmental researches, as different mesuring sites around the world (including Estonia) provide sufficient and userfriendly data for that.

Keywords:
Carbon sink, net ecosystem exchange, greenhouse gas concentration, carbon biosequestration, SMEAR station Järvselja

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Juhendaja(d): Steffen M. Noe, PhD
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<tr><td colspan="4">IPCC eriaruandes „Kliimamuutused ja maa” on metsaökosüsteemid toodud ühe kõige kulutõhusama ja teostatavama süsinikdioksiidi biohävitusmeetmena globaalse soojenemise taseme saavutamiseks alla 2 ° C (IPCC 2018). Selle lõputöö eesmärk on uurida metsaökosüsteemi mõju kasvuhoonegaaside kontsentratsioonidele ja selle biosekvistratviooni võimalus (Järvselja metsa näitel).

Antud uurimistöö on tehtud Integrated Carbon Observation System (ICOS), National oceanic and atmospheric administration (NOAA) ja SMEAR Järvselja andmete põhjal. Andmeid analüüsiti andmeteaduse metoodika ja vahendite abil - Pythoni programmeerimiskeele, Jypiteri keskkonna, Mathlabi tööriistakasti ja Panda raamatukoguga.

Töö tulemused näitavad, et metsaökosüsteemid biosekvistreerivad kasvuhoonegaase rohkem kui and produtseerivad neid, kuid aasta perspektiivis pole see alati nii. Kasvuhoonegaaside kontsentratsiooni ja biosekvistratsiooni mõjutavad paljud tegurid, kuigi süsinikdioksiidi kontsentratsioon tõuseb lõunapoolusest Soome tundrani peaaegu sama kiirusega (0,5–1% aastas). Seda aspekti tuleks edasi uurida, et töötada välja tõhusad meetodid maakasutuse globaalses plaanis, kuna näib, et kohalikud lahendused ei mõjuta</td></tr>
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kohalikke kasvuhoonegaaside kontsentratsioone. Eesti, Soome ja Rootsi metsade esmase kogutoodangu võrdlus vastab varasematele SMEAR-jaamade uuringutele ja kinnitab, et see langeb lõunalaiustelt põhja poole.

See võib viidata globaalse kliimasoojenemisest tingitud esmatootmise võimalikule kasvule.

Selle töö tulemused julgustavad keskkonnauuringute jaoks laiemalt kasutama andmeteaduslikke meetodeid, kuna kogu maailma (sh Eesti) erinevad mõõtmise jaamad pakuvad selleks piisavalt ja kasutajasõbralikke andmeid.

Märksõnad: Süsiniku valamu, ökosüsteemi netovahetus, kasvuhoonegaaside kontsentratsioon, süsiniku sidumine, SMEAR jaama Järvselja

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INTRODUCTION

The following master thesis work is made for EMÜ as a final part of the environmental management and policy masters course which was made during years 2019-2021.

The work was guided by professor Steffen M. Noe and based on data provided by the SMEAR Järvselja station. Also for the content of the work governmental documents are used from resources of the Ministry of the environment of Estonia and Statistical department of Estonia. Information from international researches of various scientific fields are also included in the thesis work.

During this work interactions between forest ecosystems and greenhouse gases will be researched. Main goal of the study is to understand: Are forest ecosystems biosequstrating more greenhouse gases than they emit (on an examle of forest in Järvselja)? The research also covers following questions:

1. What is influencing grennhouse gas concentrations measurements

2. What is influencing biosequestration

3. Are there any differences in greenhouse gas concentrations in areas with different ecosystems

4. Are the greenhouse gas concentrations rising in Estonia with the same speed as in other parts of the world

5. Is data of SMEAR station at Järvselja correlating with data of other stations

6. Is forest biosequstration capacity covering it's emissions (on an examle of forest in Järvselja)

In first part of the work areas with abundant vegetation and areas with scarse vegetation wil l be compared to see how vegetation influences the greenhouse gas concentration and are th ere any differences in greenhouse concentrations in areas with different ecosystems. For the comparesment are chosen areas, which differ in location and ecosystem type: Järvselja, Est onia; Mauna Loa, United States; Cape point, South Africa; South Pole, Antarctica; Hyytiälä , Finland; Norunda, Sweden; Sammaltunturi, Finland.
CO2 rising speed will be analysed on base of these results. Also it would be possible to check if measurements of Järvselja station correlate with other stations in different countries. ICOS

and NOAA as one of the most relaible datasources will be used to compare with data collected on Järvselja station in Tartumaa.

In second part of the work the net ecosystem exchange (carbon exchange between the soil, the forest and the atmosphere) within the particular forest ecosystem example (Järvselja) will be analysed. This will allow to estimate is Järvselja forest biosequestrating more greenhouse gases than it emits.

In third part of the work influencing factors for greenhouse gas concentrations and biosequestration will be analysed.

For this work such data science processing tools as Python, Jupyter notebook and matplotlib toolbox were used.

Main tasks of this work were:

1. Finding statistical data of greenhouse measurements of different countries

2. Assessing the data's quality for comparison

3. Building a data processing pipeline

4. Extraction of target information

5. Translating numeric data in clear and attractive visualisations

6. Analysis of the results

Hypotheses of the research is that forest ecosystem's capacity to biosequestrate is higher than it's emissions. However, due to the complexity of this ecosystem, results may vary depending on year, season, site.

Special gratitude for this work goes to Steffen M. Noe, who provided all the needed knowledge and experience. I am also very grateful to Kalev Sepp and Lagle Lõhmus for providing an opportunity to make this study. I would like to thank all the scientists of NOAA, ICOS and SMEAR stations for patient collection of statistical measurements and free share of it.

1. LITERATURE REVIEW

1.1. Greenhouse gases

The greenhouse effect is a natural process which helps to keep our climate at the average 15 °C instead of about -18 °C. However, nowadays human activities have increased atmospheric concentrations of greenhouse gases till such level that greenhouse effect impacts the climate change (ICOS 2021).

Estonia signed the Framework Convention on Climate Change at the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992. In 1994 Estonia ratified the UNFCCC and in 2002, the Kyoto Protocol (Ministry of the environment of Estonia 2017).

The total greenhouse gas emissions in Estonia have decreased by 48.52% in the past 30 years, mainly due to the transition from a planned economy to a market economy after 1991 when Estonia regained its independence (Ministry of the environment of Estonia 2017).

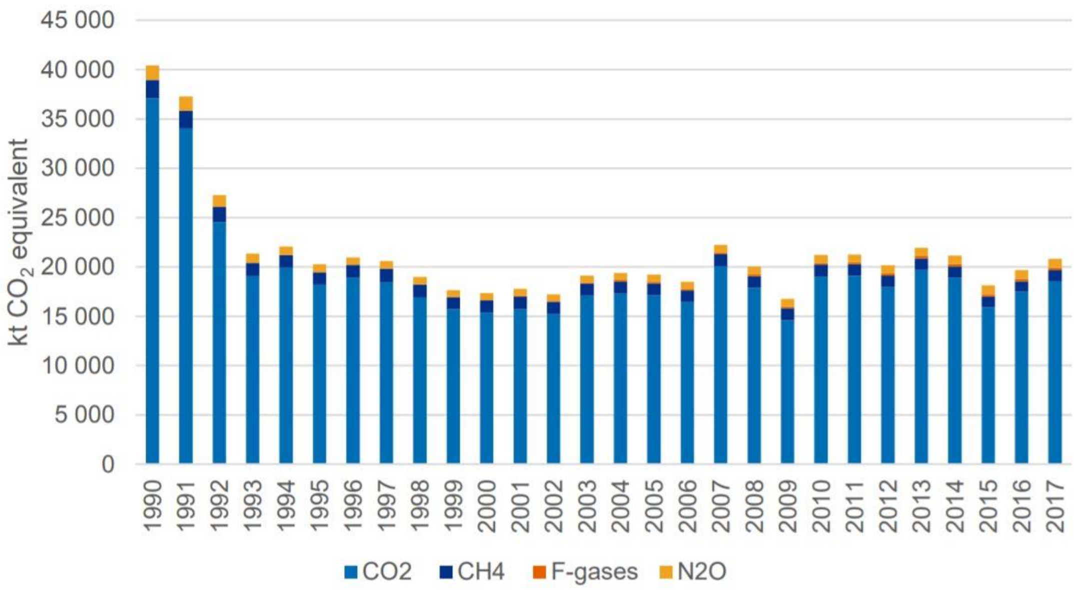


Figure 1. Estonia's greenhouse gas emissions by gas 1990–2017 (without "Land Use, Land Use Change and Forestry" sector), kilotons CO2 equivalent (Ministry of the environment of Estonia 2017).

From the graph (Figure 1) we can see that emissions from the Energy sector decreased by 49.2% compared to 1990 (incl. Energy industries – 49.7%; Manufacturing industries and construction – 78.2%; Transport – 1.4%; Other sectors – 66.2%; and Fugitive emissions from fuels – 67.7%; emissions from the sector Other increased 28.3%) (Ministry of the environment of Estonia 2017).

In this research only concentration of main greenhouse gases will be analysed, because their concentration measuring is well elaborated and takes place on most of the atmospheric stations around the world.

Carbon Dioxide (CO2)

(information defined by the national oceanic and atmospheric administration of USA in 2021, taken from the website https://www.ncdc.noaa.gov/monitoring-references/faq/greenhouse-gases.php#CO2)

The natural carbon dioxide cycle is produced and absorbed by the terrestrial biosphere and the ocean. Since the industrial revolution began in the mid 1700s, humankind had added to the cycle significant amounts of carbon dioxide by burning coal, oil, natural gas and wood.

According to ICOS, about 40% of the emissions caused by humans have remained in the atmosphere. The rest is stored on land in plants and soils, as well as in the oceans. Oceans are absorbing about 30% of CO2, but acidification is a side effect of that. However, it is not clear how effectively these CO2 sinks will operate in the future under a changing climate and increasing human impacts. (ICOS) *Anthropogenic factor is increasing in time, scale, distributions and amount.*

Carbon dioxide was the first greenhouse gas which rapid concentration increase in the atmosphere was noticed already in the last half of the 20th century. Between 1750 and 2011, about half of the emissions have occurred in the last 40 years.

Before the industrial revolution concentration was mostly stable - 280ppm. Today it is around 419 ppm, that is an increase of more than 30 percent.

The atmospheric concentration is noticeable influenced by the seasonal oscillation due to the great extent of landmass in the northern hemisphere and its vegetation. A drawdown of CO2 tend to occur in the northern hemisphere at spring and summer because plants convert

CO_2 to plant material through photosynthesis more intense then in autumn and winter period. Afterwards carbon dioxide as well as CH_4 are released in the atmosphere in autumn and winter as the plants decompose (NOAA 2021).

CH_4 (CH_4)

(information defined by the national oceanic and atmospheric administration of USA in 2021, taken from the website https://www.ncdc.noaa.gov/monitoring-references/faq/greenhouse-gases.php#CO2)

CH_4 is the second most important greenhouse gas after carbon dioxide.

Although it ads less than 0.5% of the atmospheric carbon (C) gas concentration, it contributes about 20% of the global radiative forcing (IPCC, 2013). This is because CH_4 has a much stronger radiative forcing - is 34 times stronger than CO_2. (IPCC, 2013)

CH_4's lifetime in the atmosphere is quite short compared to CO_2 - only 10-12 years.

CH_4 has both natural and anthropogenic sources. It is released as part of the biological processes in low oxygen environments, such as in swamplands or in rice production (at the roots of the plants). Over the last 50 years, human activities such as growing rice, raising cattle, using natural gas and mining coal have added to the atmospheric concentration of CH_4. Direct atmospheric measurement of atmospheric CH_4 has been possible since the late 1970s and its concentration rose from 1.52 ppmv in 1978 by around 1 percent per year to 1990, since when there has been little sustained increase. The current atmospheric concentration is approximately 1.77 ppmv, and there is no scientific consensus on why CH_4 has not risen much since around 1990 (NOAA 2021).
Global CH_4 Initiative estimates that 11% of all CH_4 emissions globally come from landfills. (Kriipsalu 2020).

1.2. Biosequestration

1.2.1. Definition of biosequestration

The most common explanation of the word biosequestration may sound as followed: "Biosequestration - is the photosynthetic assimilation of atmospheric carbon (C) by plants, as a result C is captured into plant biomass and it is partitioned to roots, where it enters the pools of soil organic and inorganic matter and can be sequestered for millennia" (Jansson, Wullschleger 2010) (Figure 2). Biosequstration can be on land (terrestrial) or in the ocean (algal growth).

More often for the same purpose is used word "sequestration", but I find it inaccurate as word "sequestration" has a wide range of meanings and can be confusing. For example, in the Oxford dictionary word "sequestration" is explained in following way: "the act of taking control of somebody's property or assets until a debt has been paid" (Oxford dictionary 2021)

There is also the 2. definition in this dictionary "the action of chemically sequestering a substance". In terms of climate or atmosphere it needs to be set into context, for example "carbon sequestration". "Chemically" is again a very wide arching term, it can be manmade or natural.

The overarching process is still carbon sequestration, and this would include beside biological processes also geological processes (which belong to physical processes). Physical processes that remove carbon are linked with burial of (usually) plant material that renders to coal, gas oil, or sediments (in oceans) and carbon is removed for long term.

For these reasons term "biosequestration" is more correct, as it indicates the relation to biological processes in natural ecosystems.

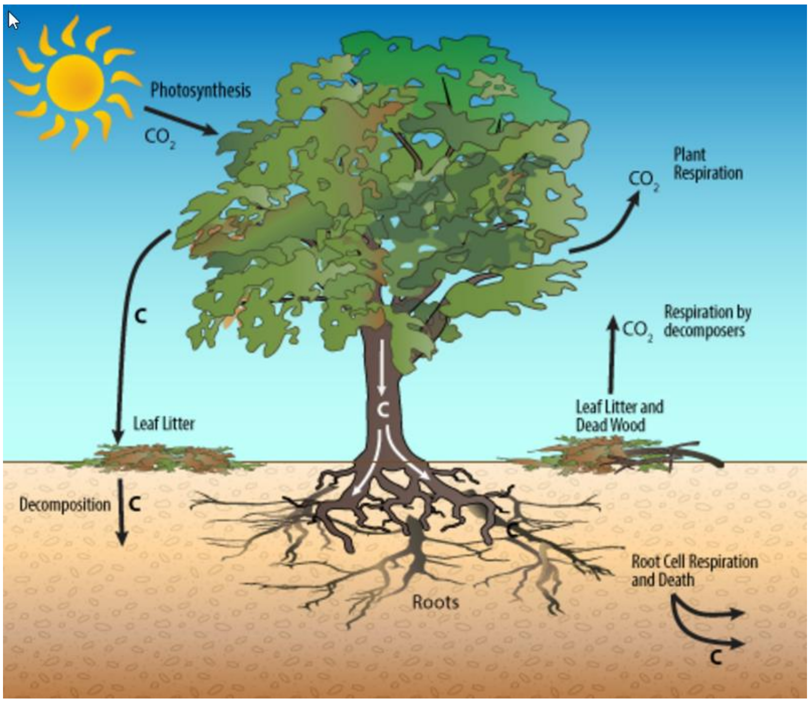


Figure 2. Biosequestration schematical process (Geogy 2021)

1.3. Forest ecosystems as carbon sinks

Greenhouse gas emissions of anthropogenic nature have essentially increased during the past century, they are the main reason of the global warming (IPCC 2013). IPCC special report 'Climate Change and Land' (IPCC 2019) emphasizes the urgent need of reorganisation actions in the land sector. The report gives the highest potential in reforestation, reducing deforestation, and bioenergy combined with carbon capture and storage. The report indicates forest and land carbon stocks as one of the most cost-efficient and feasible carbon dioxide sequestration measure to achieve global warming level under 2°C (IPCC 2018).

Carbon sink is an area of forest that is large enough to absorb large amounts of carbon dioxide from the earth's atmosphere and therefore to reduce the effect of global warming (Cambridge dictionary 2021)

Nowadays harvest level of European forests is lower than forests increment (Forest Europe 2015), and that might be seen as an option to increase biomass utilization in order to replace fossil fuels. As a consequence, wood harvesting reduces forest carbon sink potential and the required emission reductions may not be achieved (Schulze et al. 2012, Soimakallio et al. 2016, Seppälä et al. 2019 ref Kalliokoski et al. 2020).

This threat is especially present in boreal forests, which grow slower than for example tropical ones. Nevertheless, soil carbon stock plays a major role because they it is one of the most extensive global carbon storages in the world. The time for climate benefits from increased traditional wood is too long to achieve carbon related objectives of Paris Agreement (Mitchell et al. 2012, Lemprière et al. 2013, Chen et al. 2018, Dugan et al. 2018 ref Kalliokoski et al. 2020)

The need to mitigate the consequences of the climate warming made forest ecosystem's ability to sequestrate carbon highly valuable. However, biosequestration is a complex process, which requires deep understanding of the interactions between ecosystem's elements such as flora, fauna, chemical and physical processes in the soil and in the atmosphere. (Kulmala et al. 2020) Comprehensive approach is required to understand all the complexity of the ecosystem's mechanisms in details. Although many of the separated processes are already well studied, all the interactions between them are still unclear.

The definition of forest has been changed several times during the last 20 years. Since 2009, according to Estonian Forest Act, forest – is a land which meets at least one of the following requirements:

1) forest land use has been registered in land cadastre

2) it has an area of 0.1 hectares of land,

3) growing woody plants with a minimum height of 1.3 meters and the tree crown cover at least 30 percent.

Forest is the prevailing land-use category in Estonia and total forest area has increased by 84.2 kilohectares (~4 %) during the last 20 years (Ministry of the environment of Estonia 2017).

Main reason of this change is reallocation of grasslands to the Forest land category due to natural succession: when the tree crown cover exceeds 30%, the land is counted as Forest land. (Ministry of the environment of Estonia 2017).

According to GPG-LULUCF 2003 and IPCC 2006 Vol. 4, Estonia is near the transitional border of the boreal and cold temperate climatic zones, falling under the cold temperate moist climate type definition. However, most recent reports (e.g. the State of Europe's Forests 2011256) and the statement by national biologists is that Estonian forest vegetation is typical to boreal forests. This difference is important because according to new assessments the difference between temperate climate zone and boreal is significant. (Ministry of the environment of Estonia 2017).

The result was that CO2 sink increased almost on 50%, which is an obvious overestimation based on expert opinions and does not follow the UNFCCC recommended conservative approach. Guided by these results, Estonia has decided to use boreal climate zone parameters in the Forest land category.

In Estonia the "Land Use, Land Use Change and Forestry" sector is acting as the only possible sink of greenhouse gas emissions in Estonia. It plays a crucial role in the national carbon cycle, especially forest ecosystems. In 2017 the LULUCF sector acted as a CO2 sink, totalling uptake of 1792.81 kt CO2 equivalent. Compared to the base year (1990), uptake of CO2 in LULUCF sector has increased by 20.4% and compared to the previous year (2016) decreased by 34.7% (Ministry of the environment of Estonia 2017). The main drivers behind the LULUCF sector sink are harvest rates and wood production. A key driver behind the harvest trend has been the socio-economic situation in Estonia. The majority of CO2 removals in the LULUCF sector comes from the biomass increment in forest land.

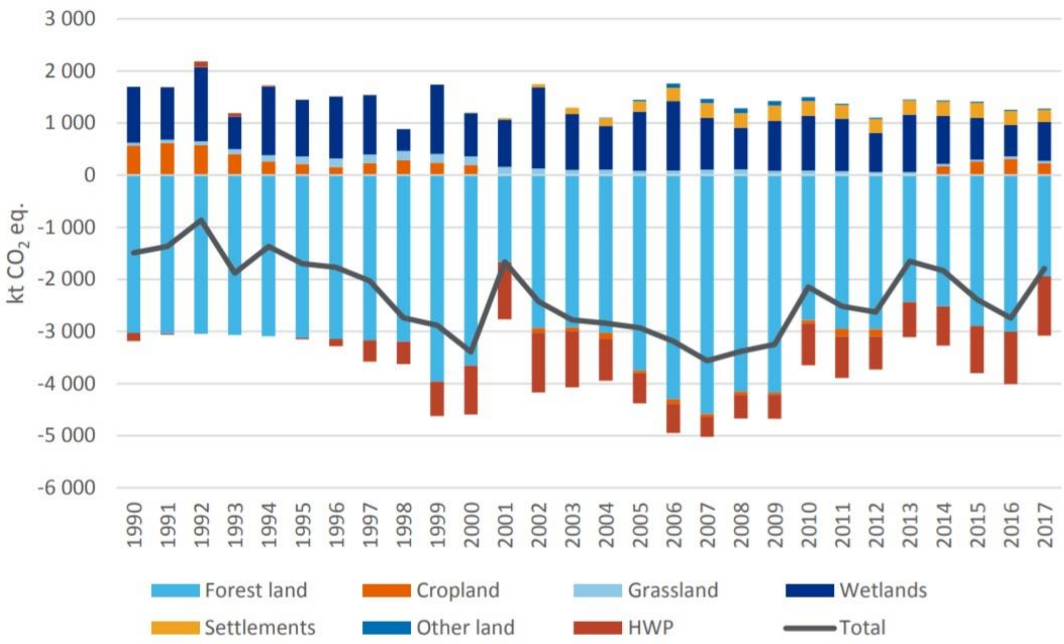


Figure 3. Trend in emissions from land use, land-use change and forestry sector 1990–2017, kiloton CO2 equivalent (Ministry of the environment of Estonia 2017).

On the figure 3 we can see that forest lands and hardwood production are the main categories which are sequestrating carbon. Wetlands are one of the main emitters of greenhouse gases, as well as croplands and settlements (Ministry of the environment of Estonia 2017).

1.4. Emissions of the forest ecosystems

Soil respiration

In the forested ecosystems, soil respiration is a major component of CO2 exchange, it creates the largest C flux from the ecosystem to the atmosphere (Janssens et al. 2001 ref Ryhti et al. 2020). Soil CO2 emissions come from soil respiration which consists of autotrophic respiration of tree roots, activity of symbiotic mycorrhizal fungi and nonsymbiotic heterotrophic microbes, such as saprotrophic bacteria and fungi. All of these play an essential role in soil organic matter decomposition (Kutsch et al. 2010, Kuzyakov 2006 ref Ryhti et al. 2020)

In summer months soil respiration is generally more active (Krasnova et al. 2019)

Identifying and understanding the sources of C in the ecosystem is challenging, because the processes responsible for different C emissions and sequestration are tightly interconnected and affected by same environmental drivers (Kuzyakov 2006 ref Ryhti et al. 2020). However, the research executed by SMEAR II station in 2013-2015 (Figure 4) in a mature Scots pine (*Pinus sylvestris* L.) stand in southern Finland have managed to separate sources of (CO2) emissions below the ground and understand it’s proportional partition (Ryhti et al. 2020). Research made in a Scots pine stand in southern Finland shows that plant roots play a significant role in soil chemistry and C sequestration, the ground vegetation species tend to suppress the heterotrophic activity and thus lower the forest floor CO2 emissions (Ryhti et al. 2020).

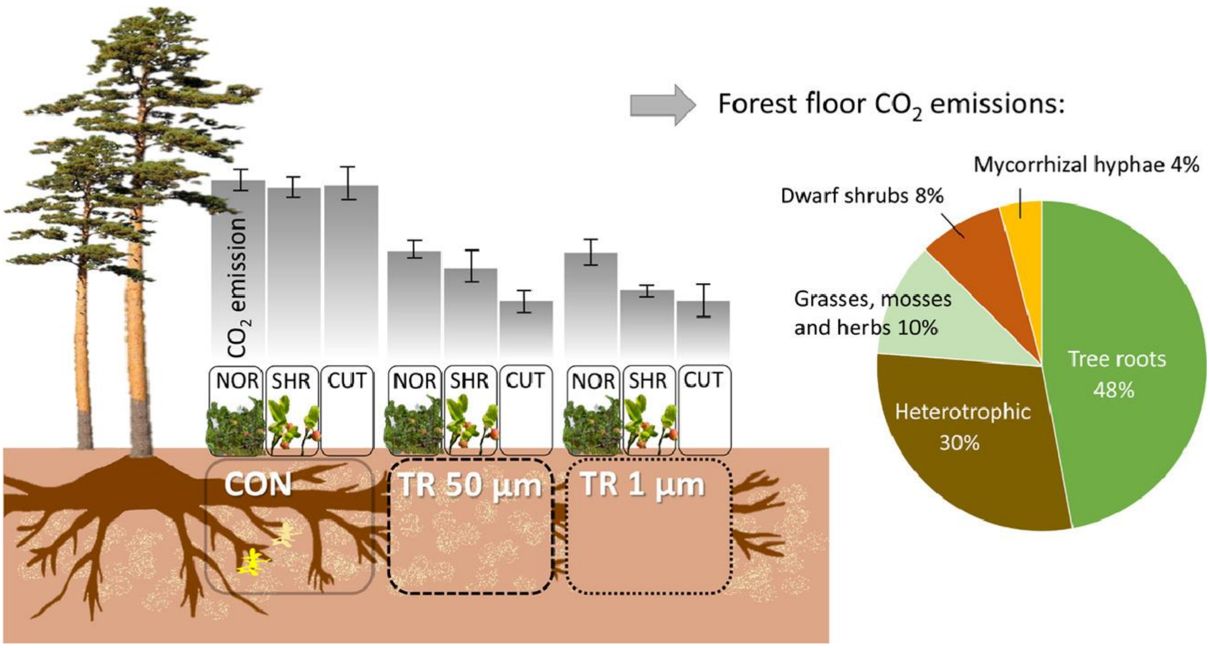


Figure 4. Results of the research made by Ryhti et al. 2020 ”Partitioning of forest floor CO2 emissions in a Scots pine stand in southern Finland”

(CON) control plot with roots and fungal hyphae not disturbed was included.

(TR50) excludment of roots, but not mycorrhizal hyphae (mesh with 50-µm pores), which allowed the ingrowth of mycorrhizal fungi, but not the plant roots

(TR1) excludment of roots and mycorrhizal fungal mycelia (mesh with 1-µm pores), which allows water and nutrients to flow through, but supresses the ingrowth of plant roots and plant-associated mycorrhizal fungi

(NOR) control plot with vegetation left intact

(SHR) left only the dwarf shrubs such as ericaceous

(CUT) removing the vegetation

However, results of the research made on SMEAR station in Järvselja, Estonia support the hypothesis according to which C is sequestered mainly in tree biomass whereas litter input into the soil is balancing the heterotrophic respiration. (Krasnova et al. 2019)

Natural aerosols

Ecosystems play an important role in the climate formation by affecting the accumulation of carbon dioxide and other greenhouse gases in the atmosphere and by being a major source of natural aerosols (Pöschl 2005, Guenther et al. 2012, Heimann and Reichstein 2008, Ballantyne et al. 2012 ref Ryhti 2020).

Atmospheric aerosols are effecting planet's radiative budget by reflecting and absorbing radiation and also by acting as cloud condensation nuclei (Kerminen et al. 2012, Paasonen et al. 2013, Charlson et al. 1992 ref Kalliokoski et al. 2020)

Some authors (Betts 2000, Unger 2014, Popkin 2019, Naudts et al. 2016 ref Kalliokoski et al. 2020) argue that in high latitudes boreal forests contribute to climate warming rather than cooling due to decreased surface albedo of the forests comparing to the clear-cuts. Especially in the European temperate forests, because forest management favours conifers, which have the lowest albedo year round. Their conclusion was based on carbon sequestration together with albedo and evapotranspiration impacts, but did not include the secondary organic aerosol effects (Kalliokoski et al. 2020), (Kulmala et al. 2020).

The research made on SMEAR II station in Finland combined for the first time the forest harvest level effect on carbon sequestration in forests and wood products, the surface albedo of forests, the direct and indirect influence of secondary organic aerosols and the avoidance of fossil emissions by product substitution. The differences between harvesting scenarios were almost entirely based on the difference of carbon impacts, because the surface albedo and secondary organic aerosol effects largely counterbalanced each other (Kalliokoski et al. 2020).

Conclusion of this study reveals that forest and atmosphere researches must take into account all possible driving forces, otherwise the results way vary significantly. Authors of this study came to the conclusion that the lesser boreal forests are harvested, the more climatic cooling effect they provide (Kalliokoski et al. 2020).

These results should be taken into account in policy making, which nowadays tends to increase use of forest biomass for short-living products and bioenergy, what is not an efficient measure to mitigate climate change (Kalliokoski et al. 2020).

Currently, Estonia does not have country-specific emission factors for soils and litter for most of the land-use categories, estimations are based on emission factors from the Sweden National Inventory Report 2018241 (Ministry of the environment of Estonia 2017). Estonia has launched several projects aimed to elaborate on country-specific data regarding omitted pools for future submissions. The University of Life Sciences is developing country specific biomass models for the above and below ground tree components of Scots pine (Pinus sylvestris), Norway spruce (Picea abies) and birch (Betula sp.).

CH4

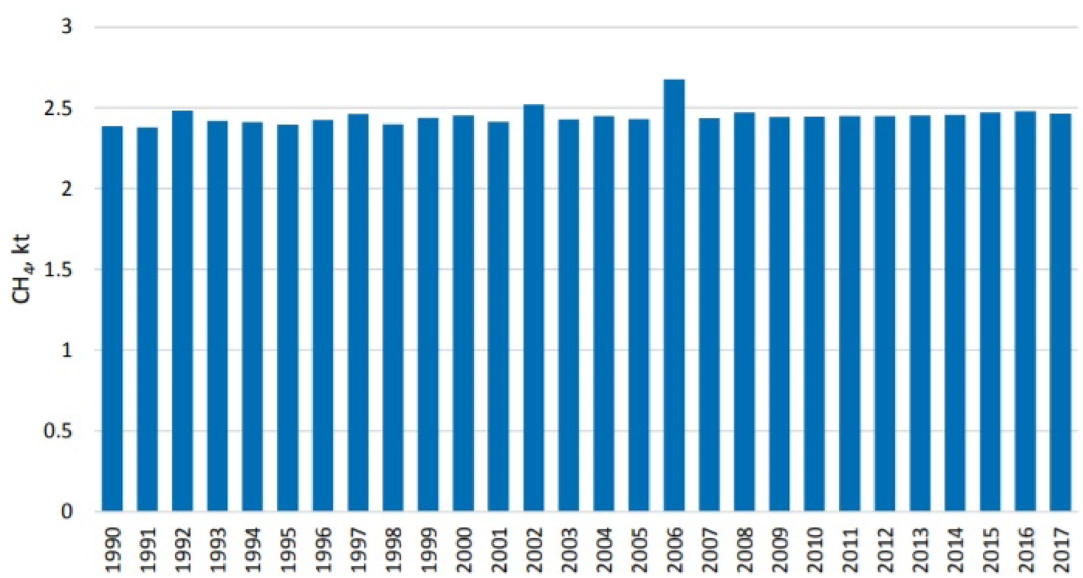


Figure 5. Emissions of CH4 from the LULUCF sector in Estonia in 1990–2017, CH4 kt

CH4 emissions originate from forest, grassland and wetland wildfires and drained organic soils (Forest land and peat extraction areas) (Ministry of the environment of Estonia 2017).

Approximately, 40% of CH4 emissions are from natural sources, mainly wetlands, while the rest (60%) are due agriculture, livestock grazing and waste and fossil fuel (Denman et al., 2007 ref Rydin & Jeglum 2006). Northern peatlands (i.e., latitude 40°–70°N) emit about 36 Tg CH4-C per year (Zhuang et al. 2006 ref Rydin & Jeglum 2006), which is equivalent to 11% of the total CH4 emissions (Wuebbles & Hayhoe 2002) Northern peatlands represent a crucial ecosystem for regional GHG budgets because they store large amounts of C (Loisel et al. 2014). However, the ratio between decomposition and bioequestration of carbon also depends on the vegetation specie. For example, Sphagnum mosses are more resistant to decomposition compared to vascular plants and thereby retain more carbon (Rydin & Jeglum 2006). Predicted changes in climate, including rising temperatures, changes in the amount, intensity, and seasonal distribution of precipitation could affect the hydrology in northern peatlands and by that increase CH4 production (FAO 2008). It is suggested that climate change reduces the capacity of northern peatlands to absorb atmospheric carbon dioxide (Wu & Roulet 2014).

However, we can still see that the forest in Estonia are biosequestrating more greenhouse gas equivalent than they together with wetlands, croplands and settlements produce (Figure 3). Moreover, amount of CH4 in Estonia stays on the same level (Figure 5), while the forested land increases.

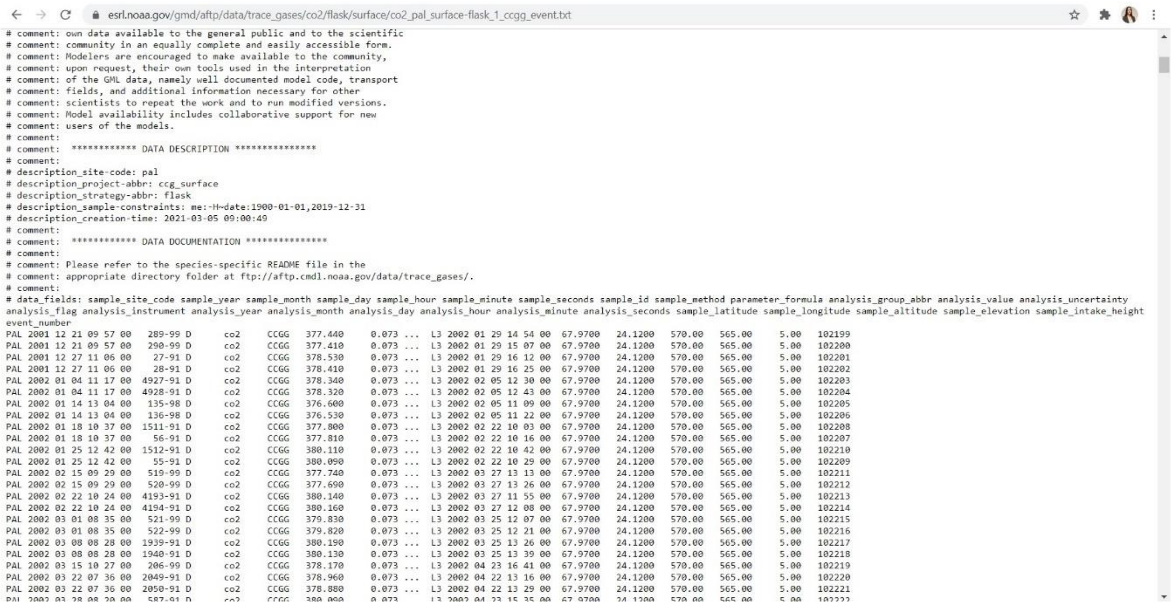
2. MATERIALS AND METHODS

2.1. Data collection

Data from different sites measuring greenhouse gases around the world was collected in order to compare their concentrations and temporal dynamics with the SMEAR Estonia station in Järvselja.

Data for comparison was taken from the most reliable and world recognised data providers, such as NOAA and ICOS. Both follow strict data quality ensuring rules and provide access to data via FAIR (Wilkinson et al. 2016) principles. SMEAR Estonia data was provided by access to the station's data repository.

This data is often stored in a "csv" format or "comma separated values" (Figure 6).



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# comment: community in an equally complete and easily accessible form.
# comment: Modelers are encouraged to make available to the community,
# comment: upon request, their own tools used in the interpretation
# comment: of the GML data, namely well documented model code, transport
# comment: fields, and additional information necessary for other
# comment: scientists to repeat the work and to run modified versions.
# comment: Model availability includes collaborative support for new
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# comment:
# comment: Please refer to the species-specific README file in the
# comment: appropriate directory folder at ftp://aftp.cmdl.noaa.gov/data/trace_gases/.
# comment:
# data_fields: sample_site_code sample_year sample_month sample_day sample_hour sample_minute sample_seconds sample_id sample_method parameter_formula analysis_group_abbr analysis_value analysis_uncertainty
analysis_flag analysis_instrument analysis_year analysis_month analysis_day analysis_hour analysis_minute analysis_seconds sample_latitude sample_longitude sample_altitude sample_elevation sample_intake_height
event_number
PAL 2001 12 21 09 57 00   289-99 D    co2    CCGG  377.440    0.073 ... L3 2002 01 29 14 54 00  67.9700  24.1200  570.00  565.00    5.00  102199
PAL 2001 12 21 09 57 00   290-99 D    co2    CCGG  377.410    0.073 ... L3 2002 01 29 15 07 00  67.9700  24.1200  570.00  565.00    5.00  102200
PAL 2001 12 27 11 06 00    27-91 D    co2    CCGG  378.530    0.073 ... L3 2002 01 29 16 12 00  67.9700  24.1200  570.00  565.00    5.00  102201
PAL 2001 12 27 11 06 00    28-91 D    co2    CCGG  378.410    0.073 ... L3 2002 01 29 16 25 00  67.9700  24.1200  570.00  565.00    5.00  102202
PAL 2002 01 04 11 17 00  4927-91 D    co2    CCGG  378.340    0.073 ... L3 2002 02 05 12 30 00  67.9700  24.1200  570.00  565.00    5.00  102203
PAL 2002 01 04 11 17 00  4928-91 D    co2    CCGG  378.320    0.073 ... L3 2002 02 05 12 43 00  67.9700  24.1200  570.00  565.00    5.00  102204
PAL 2002 01 14 13 04 00   135-98 D    co2    CCGG  376.600    0.073 ... L3 2002 02 05 11 09 00  67.9700  24.1200  570.00  565.00    5.00  102205
PAL 2002 01 14 13 04 00   136-98 D    co2    CCGG  376.530    0.073 ... L3 2002 02 05 11 22 00  67.9700  24.1200  570.00  565.00    5.00  102206
PAL 2002 01 18 10 37 00  1511-91 D    co2    CCGG  377.800    0.073 ... L3 2002 02 22 10 03 00  67.9700  24.1200  570.00  565.00    5.00  102208
PAL 2002 01 18 10 37 00    56-91 D    co2    CCGG  377.810    0.073 ... L3 2002 02 22 10 16 00  67.9700  24.1200  570.00  565.00    5.00  102207
PAL 2002 01 25 12 42 00  1512-91 D    co2    CCGG  380.110    0.073 ... L3 2002 02 22 10 42 00  67.9700  24.1200  570.00  565.00    5.00  102210
PAL 2002 01 25 12 42 00    55-91 D    co2    CCGG  380.090    0.073 ... L3 2002 02 22 10 29 00  67.9700  24.1200  570.00  565.00    5.00  102209
PAL 2002 02 15 09 29 00   519-99 D    co2    CCGG  377.740    0.073 ... L3 2002 03 27 13 13 00  67.9700  24.1200  570.00  565.00    5.00  102211
PAL 2002 02 15 09 29 00   520-99 D    co2    CCGG  377.690    0.073 ... L3 2002 03 27 13 26 00  67.9700  24.1200  570.00  565.00    5.00  102212
PAL 2002 02 22 10 24 00  4193-91 D    co2    CCGG  380.140    0.073 ... L3 2002 03 27 11 55 00  67.9700  24.1200  570.00  565.00    5.00  102213
PAL 2002 02 22 10 24 00  4194-91 D    co2    CCGG  380.160    0.073 ... L3 2002 03 27 12 08 00  67.9700  24.1200  570.00  565.00    5.00  102214
PAL 2002 03 01 08 35 00   521-99 D    co2    CCGG  379.830    0.073 ... L3 2002 03 25 12 07 00  67.9700  24.1200  570.00  565.00    5.00  102215
PAL 2002 03 01 08 35 00   522-99 D    co2    CCGG  379.820    0.073 ... L3 2002 03 25 12 21 00  67.9700  24.1200  570.00  565.00    5.00  102216
PAL 2002 03 08 08 28 00  1939-91 D    co2    CCGG  380.190    0.073 ... L3 2002 03 25 13 26 00  67.9700  24.1200  570.00  565.00    5.00  102217
PAL 2002 03 08 08 28 00  1940-91 D    co2    CCGG  380.130    0.073 ... L3 2002 03 25 13 39 00  67.9700  24.1200  570.00  565.00    5.00  102218
PAL 2002 03 15 10 27 00   206-99 D    co2    CCGG  378.170    0.073 ... L3 2002 04 23 16 41 00  67.9700  24.1200  570.00  565.00    5.00  102219
PAL 2002 03 22 07 36 00  2049-91 D    co2    CCGG  378.960    0.073 ... L3 2002 04 22 13 16 00  67.9700  24.1200  570.00  565.00    5.00  102220
PAL 2002 03 22 07 36 00  2050-91 D    co2    CCGG  378.880    0.073 ... L3 2002 04 22 13 29 00  67.9700  24.1200  570.00  565.00    5.00  102221
```

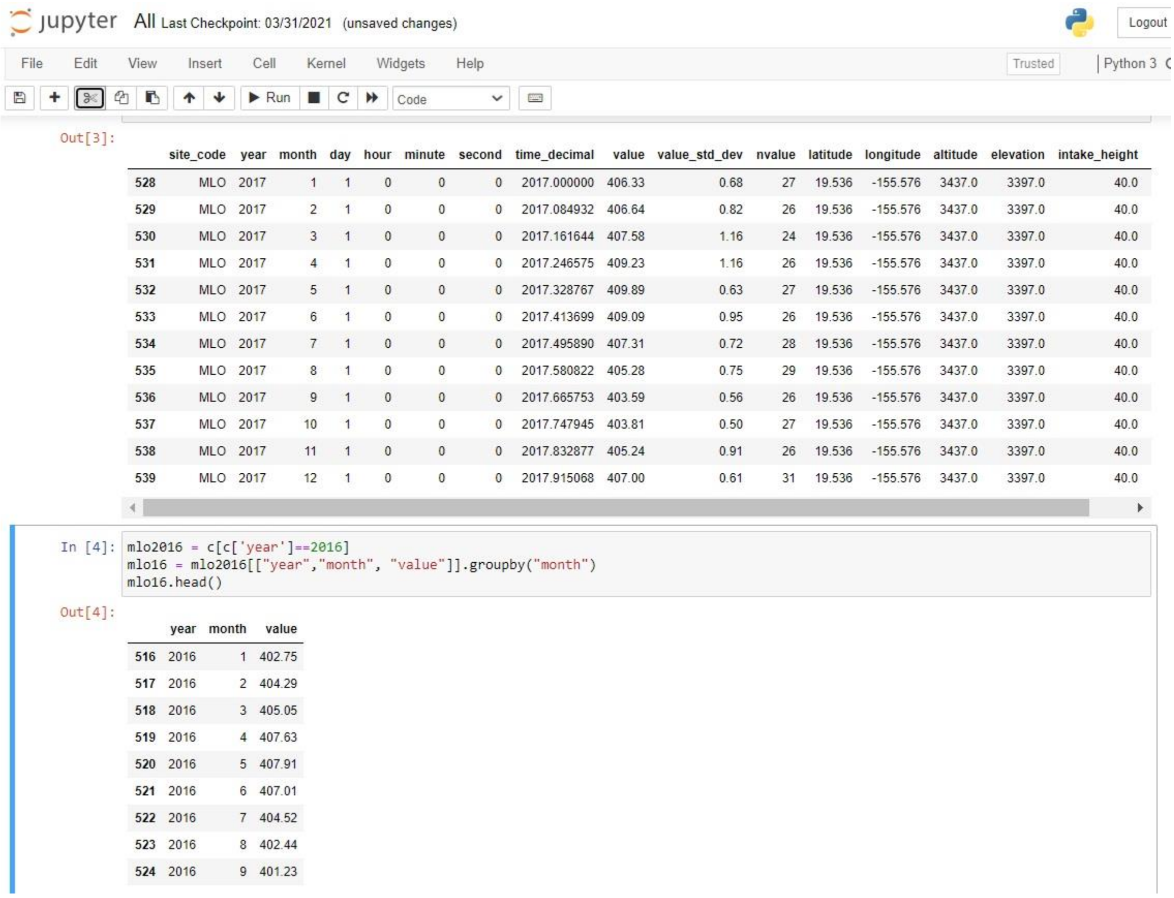
Figure 6. Data often is stored in a "csv" format or "comma separated values"

2.2. Data processing pipeline

Usually, one file contains information for decades of years, also often several measuring values are combined together.

To use this data, it must be first sorted for needed years and values.

In order to do it, data analysis and manipulation tools used it data science were applied. Most of work was done in Jupiter notebook environment, where by Python programming language special codes were elaborated to create a processing pipeline (Figure 7).



	site_code	year	month	day	hour	minute	second	time_decimal	value	value_std_dev	nvalue	latitude	longitude	altitude	elevation	intake_height
528	MLO	2017	1	1	0	0	0	2017.000000	406.33	0.68	27	19.536	-155.576	3437.0	3397.0	40.0
529	MLO	2017	2	1	0	0	0	2017.084932	406.64	0.82	26	19.536	-155.576	3437.0	3397.0	40.0
530	MLO	2017	3	1	0	0	0	2017.161644	407.58	1.16	24	19.536	-155.576	3437.0	3397.0	40.0
531	MLO	2017	4	1	0	0	0	2017.246575	409.23	1.16	26	19.536	-155.576	3437.0	3397.0	40.0
532	MLO	2017	5	1	0	0	0	2017.328767	409.89	0.63	27	19.536	-155.576	3437.0	3397.0	40.0
533	MLO	2017	6	1	0	0	0	2017.413699	409.09	0.95	26	19.536	-155.576	3437.0	3397.0	40.0
534	MLO	2017	7	1	0	0	0	2017.495890	407.31	0.72	28	19.536	-155.576	3437.0	3397.0	40.0
535	MLO	2017	8	1	0	0	0	2017.580822	405.28	0.75	29	19.536	-155.576	3437.0	3397.0	40.0
536	MLO	2017	9	1	0	0	0	2017.665753	403.59	0.56	26	19.536	-155.576	3437.0	3397.0	40.0
537	MLO	2017	10	1	0	0	0	2017.747945	403.81	0.50	27	19.536	-155.576	3437.0	3397.0	40.0
538	MLO	2017	11	1	0	0	0	2017.832877	405.24	0.91	26	19.536	-155.576	3437.0	3397.0	40.0
539	MLO	2017	12	1	0	0	0	2017.915068	407.00	0.61	31	19.536	-155.576	3437.0	3397.0	40.0

In [4]:

```
mlo2016 = c[c['year']==2016]
mlo16 = mlo2016[["year","month", "value"]].groupby("month")
mlo16.head()
```

Out[4]:

	year	month	value
516	2016	1	402.75
517	2016	2	404.29
518	2016	3	405.05
519	2016	4	407.63
520	2016	5	407.91
521	2016	6	407.01
522	2016	7	404.52
523	2016	8	402.44
524	2016	9	401.23

Figure 7. Extraction of needed values in Python (Jupiter environment) by elaboration of special codes

When data is sorted, it must be recombined so, that it’s structure will be based on the relevance of the information. For example, in this research work the most important information was the amount of CO2 and CH4 relation to the months. Hence, datasets were combined in an order which was showing relation of these two values.

After the same work was done with all the needed measuring sites, the resulted datasets were checked for compliance and balanced if needed. The data was produced in different countries, by different specialist and therefore different coding strategies and methods were needed to extract the data.

Data from NOAA was already averaged by the data producer. That was made by first averaging all valid measurement results in the event file with a unique sample date and time. Values are then extracted at weekly intervals from a smooth curve (Thoning et al. 1989 ref NOAA 2021) fitted to the averaged data and these weekly values are averaged for each month to give the monthly means recorded in the files. Flagged data are excluded from the curve fitting process. Some sites are excluded from the monthly mean directory because sparse data or a short record does not allow a reasonable curve fit. Also, if there are 3 or more consecutive months without data, monthly means are not calculated for these months (NOAA 2021).
SMEAR and ICOS mesurements were collected each 30 minutes, and then averaged by month with use of function „mean“.

Sometimes „median“ function is used for this type of researches to avoid outstanding data (usually it appears to be measurement mistakes) and in this work indeed there are found this type of outstanding data points. Although these outstanding point most likely are mistakes of measurement equipment, there are no evidence to confirm this (in the scale of this work). Therefore the dessicion was to use „mean“ function instead of „median“, so that all the available data will be included in the analysis. This desicion is also more convinient due to the fact that data from NOAA, ICOS and Järvselja producers was already checked manualy by experts, hence may be considered as trustworthy (at least in the scale of this work).

However, all used data was tested with „median“ function and there were no sufficient changes found. Maximum differences between data avereged with „mean“ and „median“ was not more than 1%, hence it is not important difference for this particular research work.

Some producers (ICOS for example) tend to replace missing values with „-999“ value, which is strongly influencing the data analysis. These values were removed in case they were replacing small scale values (a single day in the year).

In case data for some months was missing, it was replaced by average of the values for the same months in other available years and indicated under the graph (for example at Norunda sight for January, February and March).

To create visualisations (graphs) and show complex information in simple, colourful and intuitively understandable way were used additional visualisation toolboxes, for example Matplotlib (Figure 8).

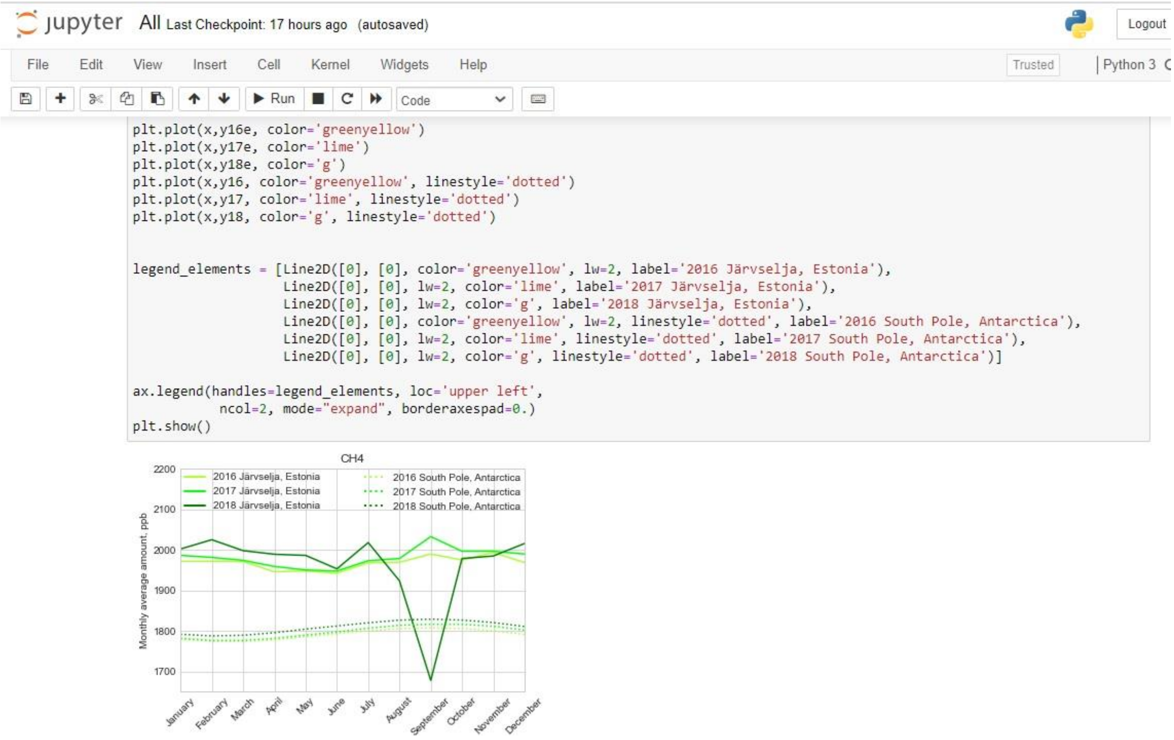


Figure 8. Complex information in simple, colourful and intuitively understandable way.

2.3. Data sources

2.3.1. SMEAR Station at Järvselja

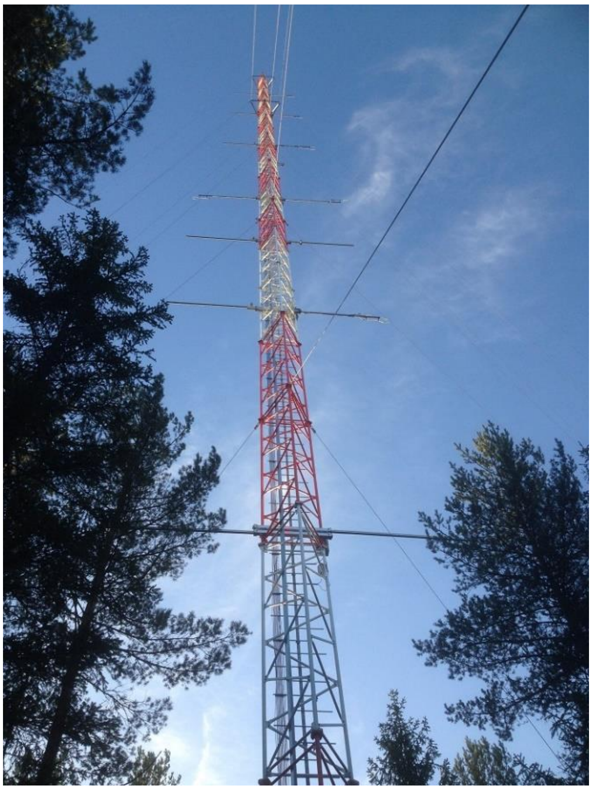
SMEAR Estonia was established in 2008 to explore the complex interactions within the eco-system-atmosphere continuum of the hemiboreal forest (Noe et al. 2011). The concept of the SMEAR Estonia station is to measure concentrations and fluxes of energy and matter in the atmosphere—biosphere system (SMEAR Estonia 2021).

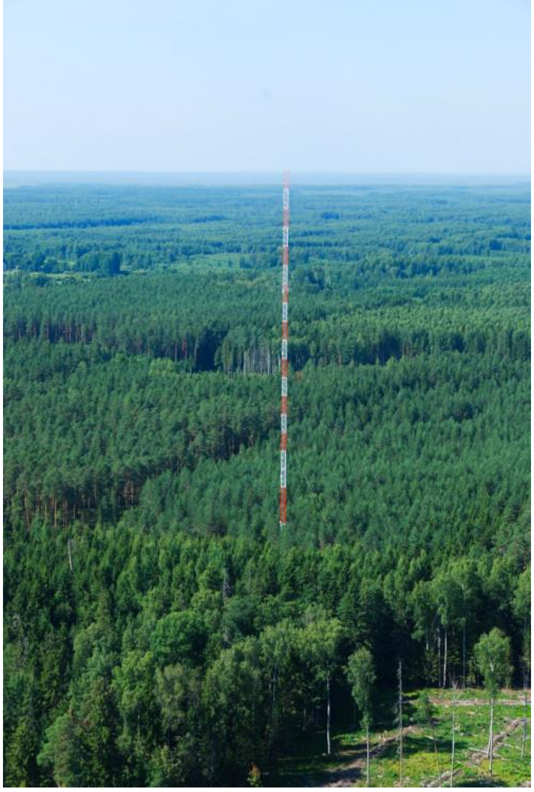
SMEAR is translated as Station for Measuring Ecosystem-Atmosphere Relation.

SMEAR Estonia is part of Estonian Roadmap Project *”Eesti Keskkonnaobservatoorium”* (Estonian Environmental Observatory). The project covers research stations all over Estonia and the aim is to do research and monitoring on atmosphere-biosphere interactions, marine and limnological sciences and land ecosystems (SMEAR Estonia 2021).

SMEAR Estonia is a part of SMEAR Station Network, which also includes 4 stations in Finland (Värriö, Hyytiälä, Helsinki, Kuopio-Puijo) and 2 stations in China (Nanjing, Beijing).

Smear Estonia participates in the ERA-Planet network and the Pan Eurasian Experiment. The SMEAR Estonia also participates in the ACTRIS network as associated partner through it’s partners - the Institute of Physics, University of Tartu (Noe et al. 2015)





Figures 9. and 10. The 300 meter (m) tower of SMEAR Estonia station in Järvselja (SMEAR Estonia 2021)

Location of the station

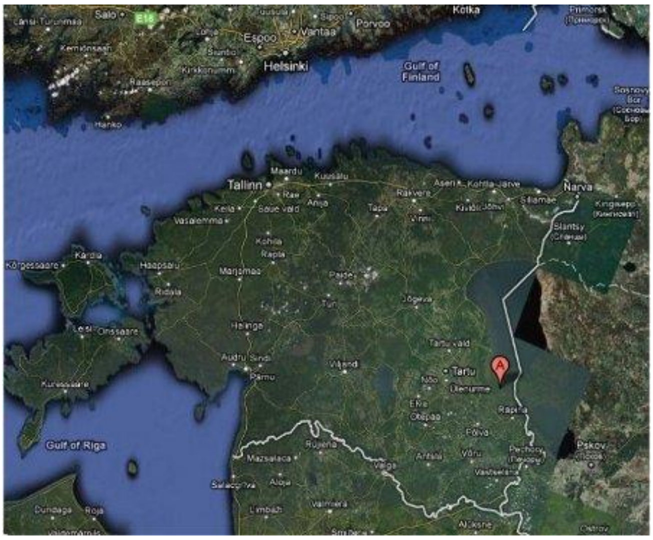


Figure 11. Location of the SMEAR Estonia station in Järvselja (SMEAR Estonia 2021)

SMEAR Estonia is established in south east Estonia at the Järvselja Experimental Forestry station (Figure 11). Additional structures in direct connection are the ”Free Air Humidifcation Manipulaton” (FAHM) experimental site at Rõka (also Järvselja) and meteorological research at Valgjärve (near Põlva) 300 m tower (Figures 9 and 10) (SMEAR 2021).

From the point of geobotanical view the forest type around the SMEAR Estonia station can be generally describes as hemi-boreal, as it lies between the temperate and subcritical (boreal) climate zones. The experimental centre covers 10,408 hectares from which 62.7% are forest ecosystems (6,526 ha) and 30.2% is wetland (3,147 ha). (Noe et al. 2015).

The climate is influenced by continental air masses from Siberian plains and Peipsi lake from the east side, Northern Fennoscandia and the coast of the Baltic Sea from the north side. The mean annual temperature is 4–6 °C and mean annual precipitation is 500–750 mm from which about 40–80 mm falls as snow. (Noe et al. 2015) The length of the growing season (with daily air temperature above 5°C) ranges between 170 and 190 days. (Noe et al. 2015).

The most common soil type is gleyed and gleyic pseudopodzolic soils, often with a raw humus horizon in wetter places. (Noe et al. 2015)

The dominant tree specie are two types of birches (Betula pendula and B. pubescens), also coniferous species such as Scots pine (Pinus sylvestris L.) and Norway spruce (Picea abies), aspen (Populus tremula L.), grey alder (Alnus incana), black alder (A. glutinosa) can be found. In some places linden (Tilia cordata) becomes increasingly dominant. Except for the native species, in the area grow in small numbers such exotic for this landscape species as fir (Abies spp.), larch (Larix spp.) and different not local pine species (Pinus spp.). These not native trees were planted by the Institute of Forestry and Rural Engineering and Estonian University of Life Sciences for experimental purposes. (Noe et al. 2015)

The stand age in the surroundings of the measurement station varies due to the past forest management practices and reaches an age of more than 100 years. The mean canopy height at the measurement mast is 20 m, but within a distance of about 300 m the oldest stands can reach up to 30 m (Noe et al. 2016).

The Järvselja village and Experimental Forestry Centre are located 1.2 km SSE of the SMEAR Estonia station and are inhabited by approximately 40 people. The village together with the road network consisting of primarily gravel roads is the only local pollution source that can occasionally affect the measurement site. The cities nearest to the site are Tartu (about 100 000 inhabitants, 36 km NW) and Pskov (about 205 000 inhabitants, 79 km SE across lake Peipus), but both are located outside the major wind direction coming towards the station (Noe et al. 2016)

According to atmospheric gas concentrations, the landscape around the tower can be named remote, rural, with low anthropogenic disturbances, location is far away from big cities and industrial regions (Noe et al. 2011).

2.3.1.1. Data collecting and proceeding methodology

The most important trace gases measured at the SMEAR Estonia station are carbon dioxide (CO_2), water vapour (H_2O) and CH_4 (CH_4), which are called greenhouse gases because of their ability to absorb and emit infrared radiation and by that propagate heat storage and transfer within the atmosphere; reactive trace gases measured are ozone (O_3), nitrogen oxides ($NO_x = NO + NO_2$) and sulphur dioxide (SO_2) (Noe et al. 2015)

SMEAR Estonia (Noe et al. 2015) uses an automated in-situ sample system that draws air samples from currently 5 heights above the forest. The atmospheric tower has inlets on 30, 50, 70, 90, and 110 m height. Each inlet is connected via 220 m long teflon pipe, 14 mm inner diameter, to a manifold system. The airflow within the pipes is 30 l/min and the travel time to the manifold is 1.13 minutes. At the manifold, a 5 l/min aliquot sample is diverted from each height and directed to the analyser rack. The manifold switches each 2 minutes from one height to another and a full cycle is completed within 10 minutes. To avoid sample air mixing, the analysers ignore the first minute after switching to flush the piping system from previous height air. Then, one minute measurements are taken and data are recorded in 10 second intervals and averaged by median.

For carbon dioxide (CO2), CH4 (CH4) and water vapour we use currently LGR GGA (Los Gatos Research Inc., USA) which uses Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS) technique. To all data we apply calibration factors and automated spike removal for signals larger that 3 x the standard deviation calculated over 30 minutes. (Noe et al. 2015)

2.3.2. National oceanic and atmospheric administration

Figure 12. Logo of National oceanic and atmospheric administration (NOAA 2021)

National oceanic and atmospheric administration (NOAA) is an agency of the U.S. government that enriches life through science. NOAA's roots reach back more than 200 years, it was one of the first America's physical science agency.

As NOAA states it, it’s mission is to better understand the natural world and help protect its precious resources beyond national borders, to monitor global weather and climate, especially underlined is work with partners around the world.

NOAA holds leadership role in policy elaboration for international ocean, fisheries, climate, space and weather. NOAA’s research programs, vessels, satellites, science centers, laboratories, scientists and experts — are internationally recognized resources.

2.3.2.1. Data collecting and proceeding methodology

Each data file includes a prepared data set and associated metadata. Each data file includes the sample collection time, position, reported mole fraction or isotope ratio, estimated uncertainty and other relevant information. Metadata describe general features of the data set and characteristics of the variables associated with each data item.

2.3.3. Integrated Carbon Observation System

Figure 13. Logo of Integrated Carbon Observation System

(https://www.icos-cp.eu/sites/default/files/2020-04/ICOS%20RI_logo_rgb.png)

Integrated Carbon Observation System (ICOS) is a research infrastructure that has been born out of European scientific communities' grand idea of having a consistent, sustained measurement network operating under the same standards to enable high-quality climate change research and increase the amount of the research data.

Mission of ICOS is to produce standardised, high-quality and long-term observation measurements on greenhouse gases. ICOS aims to provide information for policy- and decision-making to combat climate change by linking research, education and innovation with high-precision data. ICOS data helps to monitor the Earth systems and their response to climate change and other environmental issues.

ICOS brings together and support the European high-quality research and measurement stations and elaborate research infrastructure that serves the scientists, as well as the society. Since December 2019 ICOS has been an Observer to the United Nations Framework Convention on Climate Change (UNFCCC). ICOS supports the UNFCCC in it's goals to follow the Paris Agreement.

2.3.3.1. Data collecting and proceeding methodology

The ICOS processed data products are mostly time-series of observed variables, for example atmospheric carbon dioxide concentrations, given for every 30-minute interval.

The following diagram produced by ICOS shows the standardised ways of handling data within ICOS system:

ICOS data follows the international developments and standardisation. ICOS data and metadata are Findable, Accessible, Interoperable, and Reusable, and follow so called FAIR principles. In practice, the FAIR principles aim to give the user sufficient tools to use the data before and after downloading it.

Standard of the Infrastructure for Spatial Information in Europe (INSPIRE) is followed, and is based on the ISO 19115 metadata standard.

All the stations have to go through the demanding standardisation and quality control programme of ICOS, in order to meet the high standards and to receive the label for standardised measurement station. The station labelling is an integrate process for final implementation of ICOS standards and compliance check for the stations. Approval by the national government is needed for station labelling.

50 ICOS measurement stations out of 140 countries have been standardised for greenhouse gas measurements (as for 2020).

2.4. Calibration

For calibration purposes a high quality pure gas is used. It is produced in a special laboratory in Belgium (Metrology for climate relevant volatiles compounds 2021).

All European monitoring stations which participate in ICOS collaboration use this source of gas as reference, as it is defined by European Air Quality Directive 2008/50/EC regulations. Usually, station equipment is calibrated with reference high quality gas once a month, but Järvselja is provided by this gas only occasionally by Finnish colleagues and therefore can not calibrate the equipment sufficiently enough. SMEAR Station can not join ICOS or any other international collaboration parties before the supply of reference gas will be sufficient and stable, what must be organised on the governmental level. However, at the moment governmental authorities do not cooperate in order to include Estonia in international collaboration parties (for example ICOS).

2.5. Data uncertainty

Many efforts are made to provide the most certain and relaiable data, however there are enormous ammount of factors existing in any process, each of them may behave unpredictable and influence the measurements. Technical equipment usually consists of a highly difficult devices and programs, which may be hard to balance. Hence, sometimes mistakes occur in measurement collection. Usually they are fixed, replaced or elliminated by the manual adjusments, as all raw data must be overviewed by professionals in order to correspond to high realiblity standarts.

Standart deviation (uncertanties of values) were already included in the datasets of producers (NOAA, ICOS and SMEAR). Standart deviation of values are represented in the „Results“ section near the main graphs with analysis. This allows to easier compare the results of analysis and the unsertanties of values behind them.

Standart deviation of the data correlates with the ammount of rainfall, first of all because high humidity creates dinamic for many processes (for example vegetational growth, soil respiration), secondly because high humidity makes data more uncertain – molecules of water affect the concentration of gas.

Uncertainty of measurements for NOAA data was determinated by the prodicer as followed: *the internal consistency of working standards is +/- 0.02 ppm (68% confidence interval). The typical repeatability of the analyzers, based on repeated measurements of natural air from a cylinder, is +/- 0.03 ppm. Average agreement between pairs of samples flushed in series across the entire sampling network is +/- 0.07 ppm. The uncertainty of our CH4 standard scale (NOAA 2004A) near 1800 ppb is estimated at +/- 0.2%, or about 3 nmol/mol. Uncertainties (68% c.i.) were estimated for all CO2 measurements. Uncertainty entries of -999.99 occur when a reasonable uncertainty could not be calculated. (Zhao and Tans 2006 ref NOAA 2020)*

3. RESULTS

The first part of analysis include visualisations of CO_2 and CH_4 gas concentration on different measurement sites ()

For the comparison are chosen areas with different ecosystem types (Järvselja, Estonia; Mauna Loa, United States; Cape point, South Africa; South Pole, Antarctica; Hyytiälä, Finland; Norunda, Sweden; Sammaltunturi, Finland.)

Mainly they are divided on areas with scarce vegetation and areas with abundant vegetation. This is made in order to see what specific pattern vegetation shows on the graphs and is that carbon sink.

It is not possible to simply compare greenhouse gas concentration and say that in places with low concentration ecosystem biosequestrate better, because there are many other (except for ecosystem) aspects that play a role in forming the greenhouse concentration, for example the altitude of the measurement site and the height from which the measurement was taken.

Different measurement sites are making greenhouse gas concentration measurements on different height, what makes comparison slightly difficult. The higher the measurement is taken, the lower will be the concentration and this must be taken into account while making the analysis.

As a result we can clearly see that in areas with vegetation CO_2 concentration significantly drops down in spring-summer period. The pattern repeats itself yearly. The fact that the seasonal drop down of CO_2 concentration in areas with vegetation happens because of biosequestration process proves the corelation of the dropdowns with maximum temperature and rainfall amount (main driving factors for the vegetational growth).

Since 2000, the global CO_2 average has grown by 43.5 ppm, an increase of 12 percent (NOAA 2021). NOAA’s preliminary analysis showed the annual increase in atmospheric CH_4 for 2020 was 14.7 parts per billion (ppb), which is the largest annual increase recorded since systematic measurements began in 1983.

The economic recession was estimated to have reduced carbon emissions by about 7 percent during 2020. Without the economic slowdown, the 2020 increase would have been the highest on record, according to Pieter Tans, senior scientist at NOAA's Global Monitoring Laboratory.

The atmospheric burden of CO2 is now comparable to where it was during the Mid-Pliocene Warm Period around 3.6 million years ago, when concentrations of carbon dioxide ranged from about 380 to 450 parts per million. During that time sea level was about 23 m higher than today, the average temperature was 7 degrees Fahrenheit higher than in pre-industrial times, and studies indicate large forests occupied areas of the Arctic that are now tundra (NOAA 2021).

The concentration of CO2 is rising in all the measurement sites, even without vegetation (South pole). This tells us that the concentration of CO2 does not stay local, but is transmitted over all the planet (the most south measurement site included in this research is South pole 90.0000° S, 45.0000° E, the most north - Sammaltunturi, Finland 67.9667° N, 24.1167° E). In Estonia the mean CO2 concentration is 416 ppm, which corresponds to the general global estimate.

According to this research CO2 concentration (measured in ppm) is rising with speed of 0.5% - 1% per year:

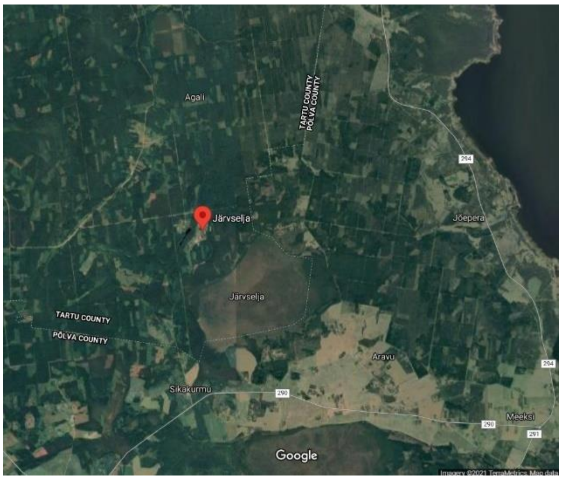
Järvselja, Estonia 0.70%
Mauna Loa, United States 0.58%
Cape point, South Africa 0.55%
South Pole, Antarctica 0.50%

Hyytiälä, Finland 1.01%

Norunda, Sweden 0.49%
Sammaltunturi, Finland 0.51%

Certainly, it must be taken into account, that these numbers derive from measurements, which were taken on different heights and altitudes. Given results correspond to the middle global estimate, which is 0.94% (CO2earth 2021). That means that in Estonia (Järvselja) the concentration of CO2 is rising slower than generally in the world.

All the measurements will be compared to SMEAR station at Järvselja, Estonia.



Figures 14. and 15. Location of the SMEAR Järvselja station on 1 km and 200 km scale (Google maps 2021)

ALTITUDE: 45 m above the sea level

SAMPLING HEIGHTS: 30 m

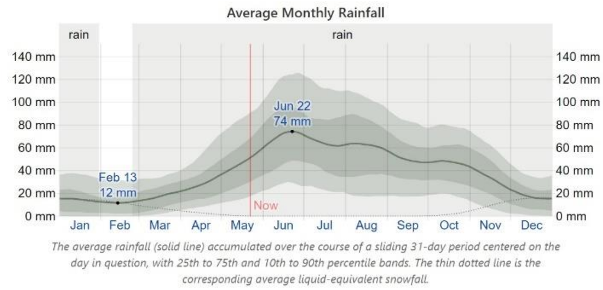
ECOSYSTEM TYPE: boreal forest with wetlands

DATA PRODUCER: SMEAR Järvselja station

DATASET DATA FREQUENCY UNIT : 30 min

MEASUREMENT METHOD: in-situ sample system draws air samples via 220 m long teflon pipe, 14 mm inner diameter, to a manifold system. The airflow within the pipe is 30 l/min and the travel time to the manifold is 1.13 minutes. At the manifold, a 5 l/min aliquot sample is diverted and directed to the analyser LGR GGA (Los Gatos Research Inc., USA) which uses Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS) technique (SMEAR 2021).

Figures 16. Surroundings of the SMEAR Järvselja station (SMEAR 2021)



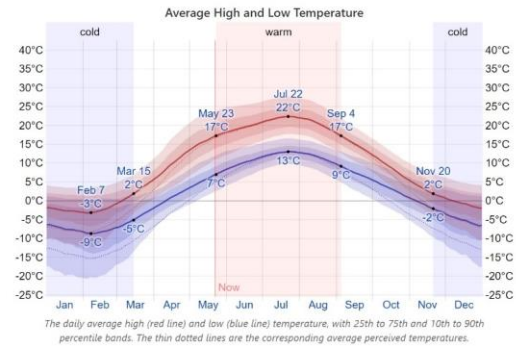


Figure 17. and 18. Average monthly rainfall and average high and low temperature for Järvselja (Weatherspark 2021).

3.1. Greenhouse gas concentration comparison

3.1.1. Areas with scarce vegetation

3.1.1.1. Mauna Loa, United States and Järvselja, Estonia

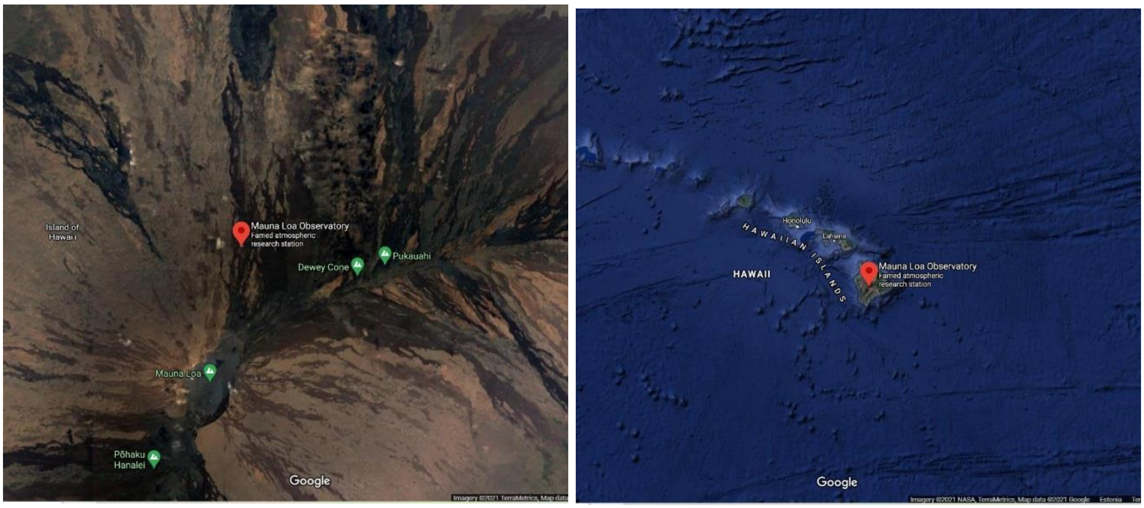


Figure 19. Location of the station on 1 km and 200 km scale (Google maps 2021)

ALTITUDE: 3437 m above the sea level

SAMPLING HEIGHTS: 40 m

ECOSYSTEM TYPE: volcanic island

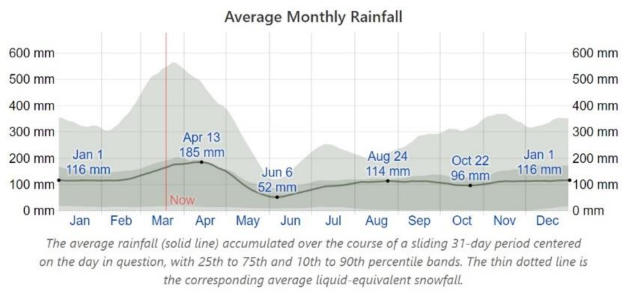
DATA PRODUCER: NOAA

DATASET DATA FREQUENCY UNIT : month

MEASUREMENT METHOD: surface-insitu, measured mole fraction of trace gas in dry air. Sample collected using a portable, battery powered pumping unit. Two flasks are connected in series, flushed with air, and then pressurized to 1.2 - 1.5 times ambient pressure.

Figures 20. Surroundings of the station (Wikipedia 2021)

Mauna Loa Observatory is located on the north flank of Mauna Loa Volcano, on the Big Island of Hawaii (Figures 19 and 20). The observatory protrudes through the strong marine temperature inversion layer present in the region, which separates the more polluted lower portions of the atmosphere from the much cleaner free troposphere. The undisturbed air, remote location, and minimal influences of vegetation and human activity at Mauna Loa This is the site of the world's longest, continuous CO2 record of direct atmospheric measurements using high-precision instruments. The location is near the middle of the world's largest ocean, and near the top of the world's tallest mountain, from its base (McGee, 2017).



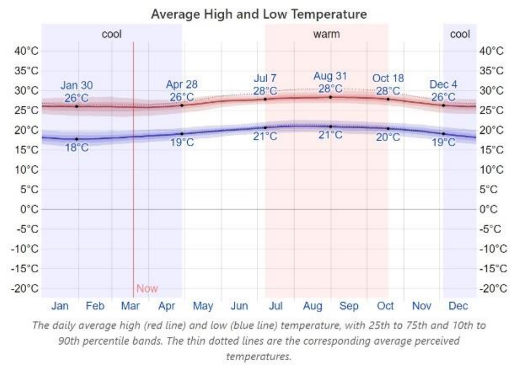


Figure 21. and 22. Average monthly rainfall and average high and low temperature for Järvselja (Weatherspark 2021).

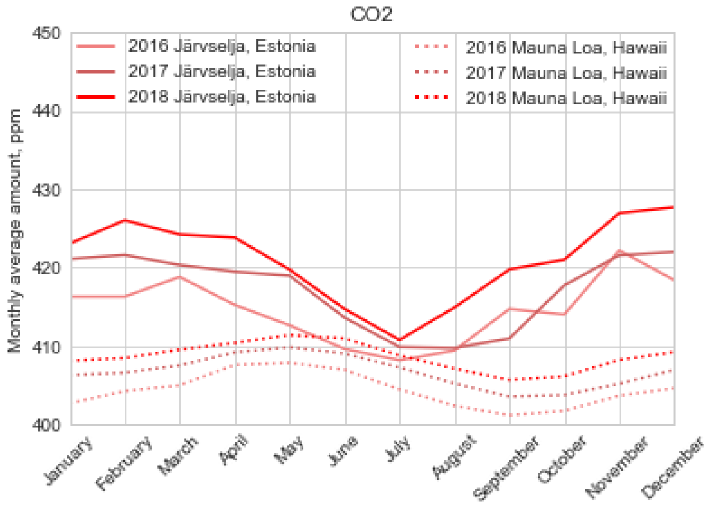


Figure 23. Monthly average of CO2 concentration in parts per million (ppm)

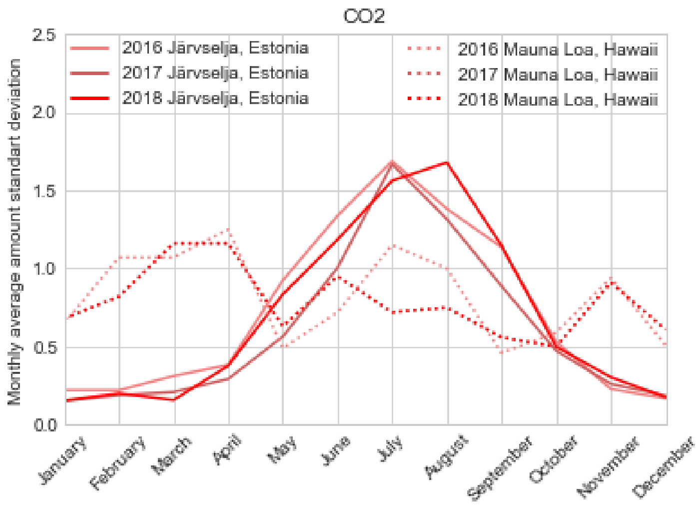


Figure 24. Standard deviation for monthly average of CO2 concentration (ppm)

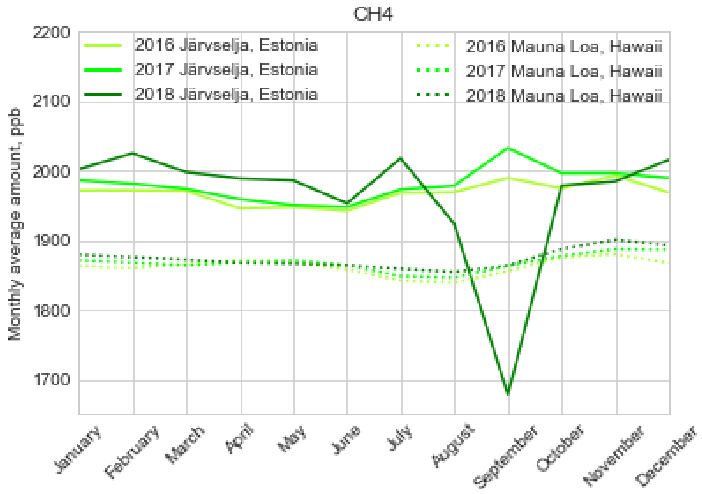


Figure 25. Monthly average of CH4 concentration in parts per billion (in ppb)

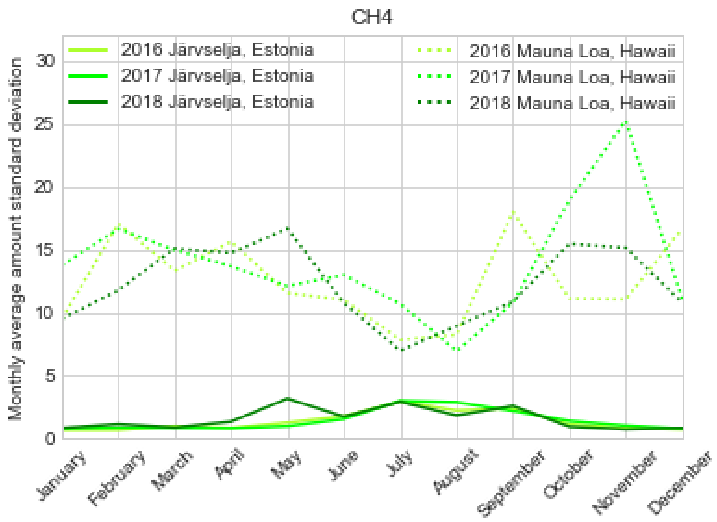


Figure 26. Standard deviation for monthly average of CH4 concentration (in ppb)

The graphs (Figure 23) show that the concentration of CO2 and CH4 on Mauna Loa is lower than in Järvselja. That can be explained by higher altutude of Mauna Loa (3437 m above see level and 46 m above see level in Järvselja) and low ammount of vegetation on a volcanic island.

Because of low seasonality (Figures 21 and 22) the dinamic of concentration of CO2 and CH4 on Mauna Loa is almost even (Figures 23 and 26). In Järvselja concentration of CO2 is always lower in summer period - CO2 is sequestarted by vegetation and soil. Concentration of CH4 in Järvselja is usually higher in autumn due to high humidity and rottening processes. The „spike“ in September is an anamaly, which is hard to enterpretaty (within this research work). With a closer look, it is clear that this is not a single outstanding value creating this spike, it is a serie of outstanding values, which gratualy increase and then lower down.

Standart deviation of the data correlates with the ammount of rainfall, first of all because high humidity creates dinamic for many processes (for example vegetational growth, soil respiration), secondly because high humidity makes data more uncertain – molecules of water affect the concentration of gas (Firuges 24 and 26)

3.1.1.2. Cape point, South Africa and Järvselja, Estonia

For this comparison is used data from stations mainly in South hemisphere or not far from it. Scarce vegetation gives an opportunity to see it’s influence on the data of Järvselja. These areas don’t have significant seasonal temperature and rainfall differences (Figures 29 and 30)

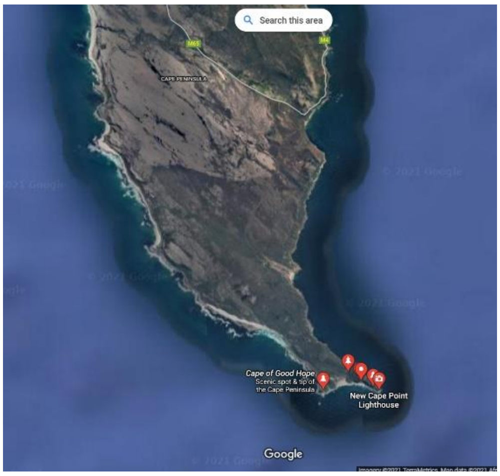


Figure 27. Location of the station on 1 km and 200 km scale (Google maps 2021)

ALTITUDE: 230 m above the sea level

SAMPLING HEIGHTS: 30 m

ECOSYSTEM TYPE: Mediterranean-type, fire-prone shrubland (https://web.archive.org/web/20140520221302/http://www.capetown.gov.za/en/EnvironmentalResourceManagement/Pages/default.aspx)

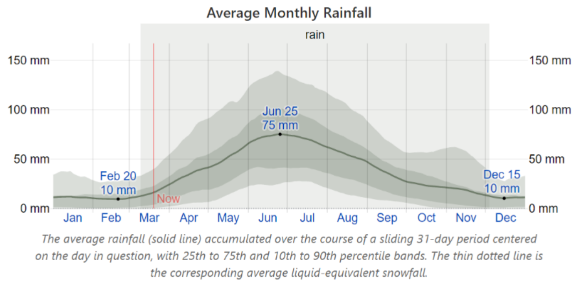
DATA PRODUCER: NOAA

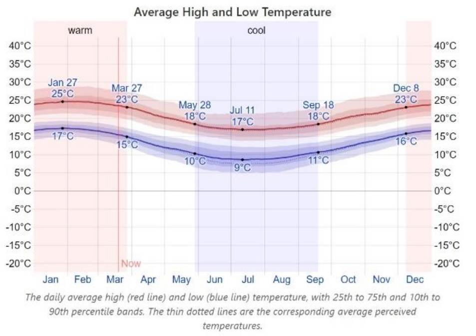
DATASET DATA FREQUENCY UNIT : approximately 2-3 times a month

MEASUREMENT METHOD: Sample collected using a portable, battery powered pumping unit. Two flasks are connected in series, flushed with air, and then pressurized to 1.2 - 1.5 times ambient pressure.The air passes through a gold-plated condenser cooled to about 5 deg C to partially dry the sample.

Figures 28. Surroundings of the station (Roselinde photos 2021)

The Cape Point station is located in a nature reserve at the southern end of the Cape Peninsula, about 60 km south from the city of Cape Town (Figures 27 and 28). The monitoring station is exposed to the sea, since the dominant wind direction is SE - S - SW, the station is subjected to maritime air from the South Atlantic most of the time. The Cape Peninsula has a Mediterranean-type climate where the summers are generally dry and windy, whilst the winters are cold and wet.





Figures 29. and 30. Average monthly rainfall and average high and low temperature for The Cape peninsula (Weatherspark 2021).

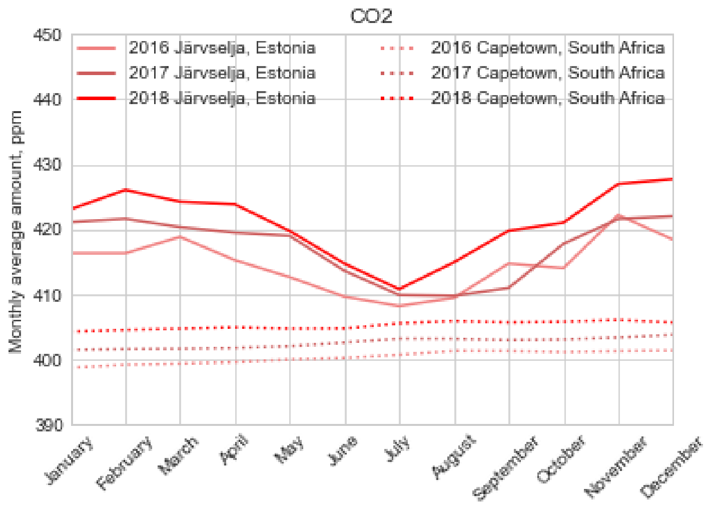


Figure 31. Monthly average on CO2 concentration (ppm)

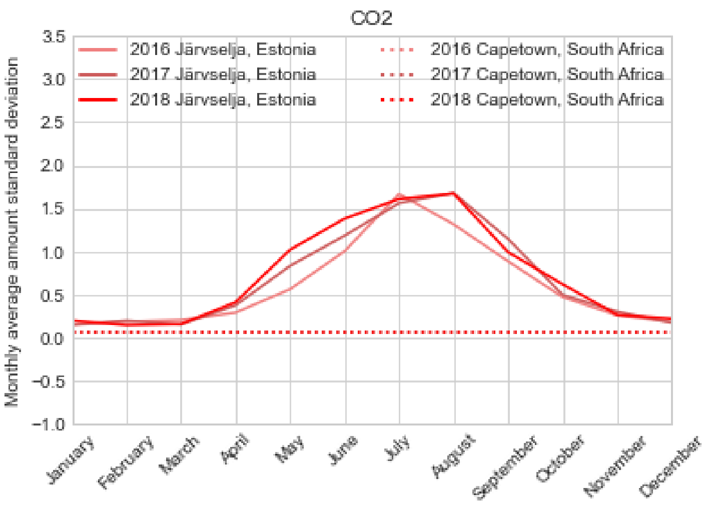


Figure 32. Standard deviation for monthly average of CO2 concentration (ppm)

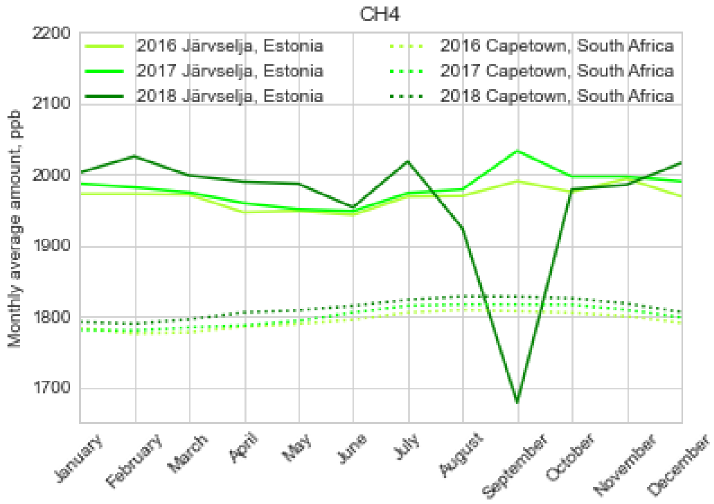


Figure 33. Monthly average of CH4 concentration (in ppb)

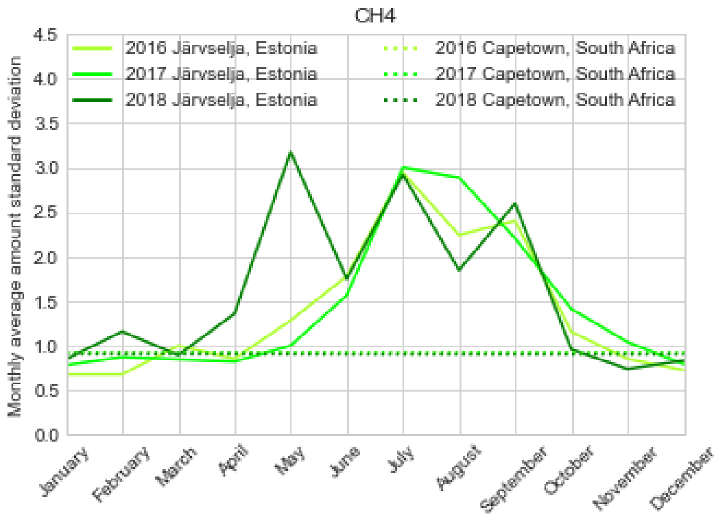


Figure 34. Standard deviation for monthly average of CH4 concentration (in ppb)

The graphs show that the concentration of CO2 and CH4 on Cape point is lower than in Järvselja. (Figures 31 and 33).That can be explained by higher altutude of Cape point (230 m above see level and 46 m above see level in Järvselja), exposure to the sea and winds and low ammount of vegetation.

Because of low seasonality the dinamic of concentration of CO2 and CH4 on Cape point is almost even. In Järvselja concentration of CO2 is always lower in summer period - CO2 is sequestarted by vegetation and soil. Concentration of CH4 in Järvselja is usually higher in autumn due to high humidity and rottening processes.

Standart deviation (Figures 32 and 34) are high in Järvselja in spring-summer periods due to many bioprocesses related to vegetatinal grow. On Cape peninsula those processes are not significant, as well as standart deviation.

3.1.1.3. South Pole, Antarctica and Järvselja, Estonia

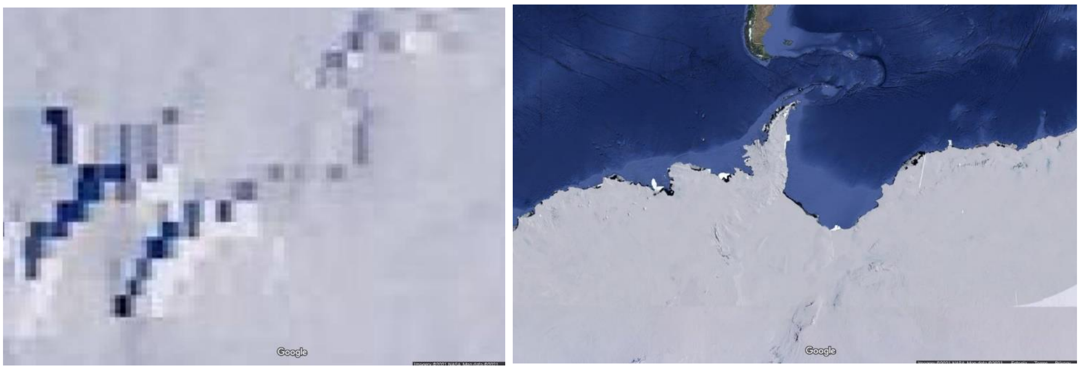


Figure 35. Location of the station on 1 km and 200 km scale (Google maps 2021)

ALTITUDE: 2821 m above the sea level

SAMPLING HEIGHTS: 11

ECOSYSTEM TYPE: polar desert

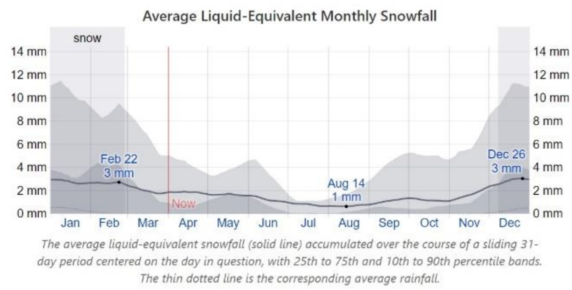
DATA PRODUCER: NOAA

DATASET DATA FREQUENCY UNIT : month

MEASUREMENT METHOD:
Sample collected using a portable, battery powered pumping unit. Two flasks are connected in series, flushed with air, and then pressurized to 1.2 - 1.5 times ambient pressure. Flasks filled at NOAA GML observatories by sampling air from the in situ CO2 measurement air intake system.

Figures 36. Surroundings of the station (Sciencealert 2019)

The South Pole Observatory is located at the geographic South Pole on the Antarctic plateau (Figures 35 and 36). A Clean Air Sector was established to preserve the unique atmospheric and terrestrial conditions from South Pole Station influences. Except for special circumstances, access to the Clean Air Sector is prohibited. This includes foot and vehicle traffic. Aircraft activity is limited in Clean Air Sector, and guidelines for scientific or other activities are under discussion at this time. The pristine nature of Clean Air Sector is strictly preserved, not just for the current scientific activities, but also for future science at South Pole. The prevailing winds at the South Pole are from Clean Air Sector more than 90% of the time.



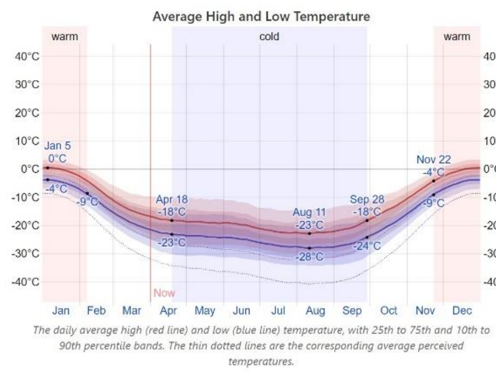


Figure 37. and 38. Average monthly rainfall and average high and low temperature for South Pole (Weatherspark 2021).

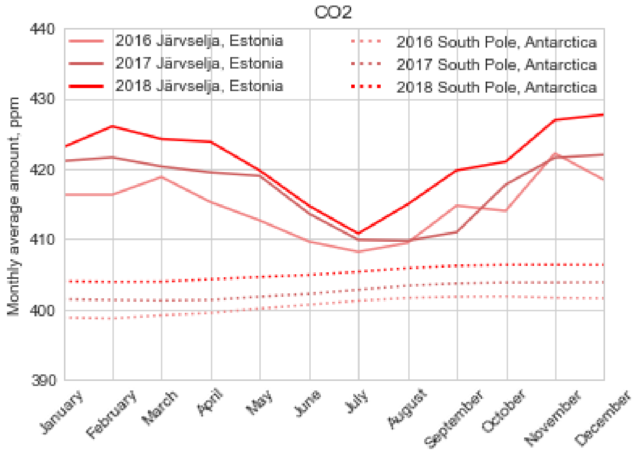


Figure 39. Monthly average on CO2 concentration (ppm)

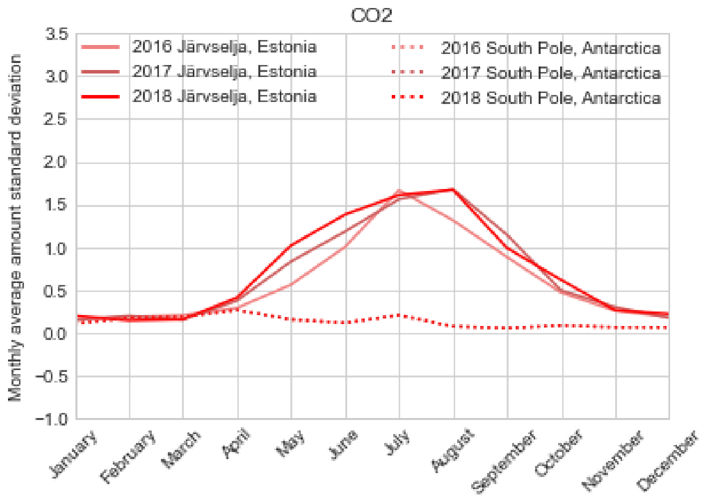


Figure 40. Standard deviation for monthly average of CO2 concentration (ppm)

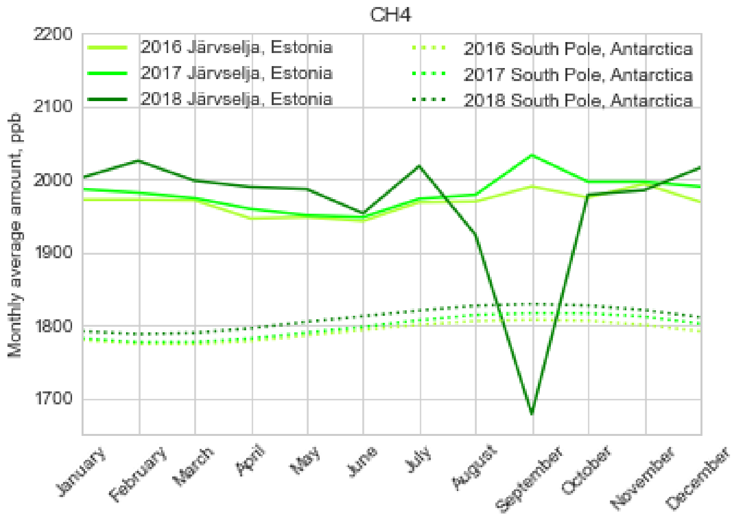


Figure 41. Monthly average of CH4 concentration (in ppb)

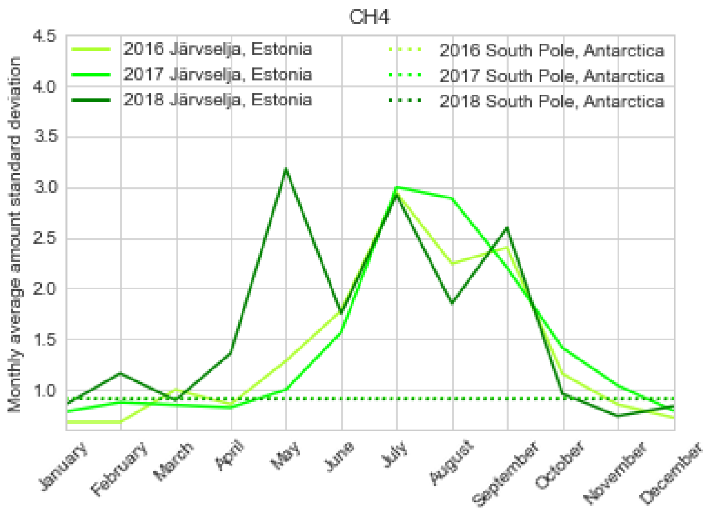


Figure 42. Standard deviation for monthly average of CH4 concentration (in ppb)

On the graphs we can see that the concentration of CO2 and CH4 on South pole is lower than in Järvselja (Figures 39 and 41). That can be explained by higher altutude of the South Pole station (2821 m above see level and 46 m above see level in Järvselja), exposure to winds and abscence of vegetation (one of the main sources of CH4). However, we can still see the trace of CH4, which can not be produced on this land but is rather transpoted here by the winds. This observation shows how volatile green gases are and on how far distances exchange of the atmosphere gases takes place.

South winds which dominate 90% of the time on South Pole station and absence of vegetation and processes in the soil makes CO2 and CH4 dynamics almost stable (Figures 37 ja 38).

Standart deviation (Figures 40 and 42) are high in Järvselja in spring-summer periods due to many bioprocesses related to vegetatinal grow. On South Pole those processes are absent and standart deviation is not significant.

3.1.2. Areas with abundant vegetation

For this comparison similar to Järvselja ecosystems like boreal forests of northern hemisphere in Finland and Sweden are taken. These areas have seasonal temperature and rainfall differences (Figures 45, 46, 53, 54, 61 and 62)

Distinguishing from the last set of examples, following data of samples is taken in period of 2017-2019 due to unavailability of data from years 2016 on the Hyytiälä and Norunda stations.

3.1.2.1. Hyytiälä, Finland and Järvselja, Estonia

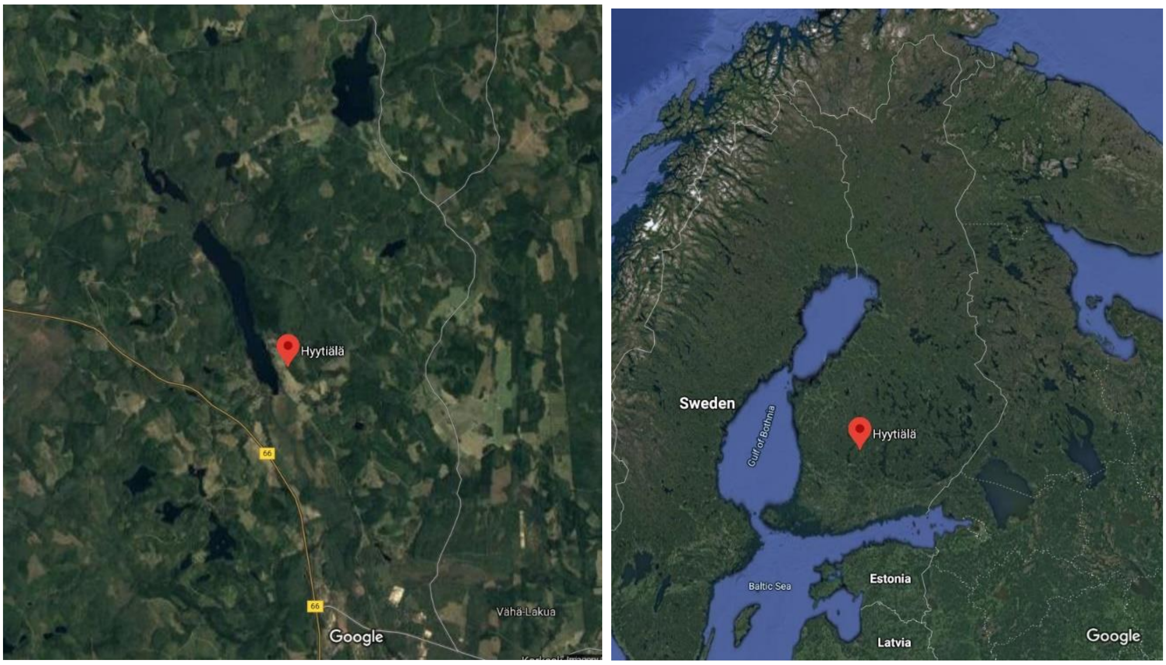


Figure 43. Location of the station on 1 km and 200 km scale (Google maps 2021)

ALTITUDE: 181 m above the sea level

SAMPLING HEIGHTS: 67.2 m

ECOSYSTEM TYPE: boreal forest with wetlands

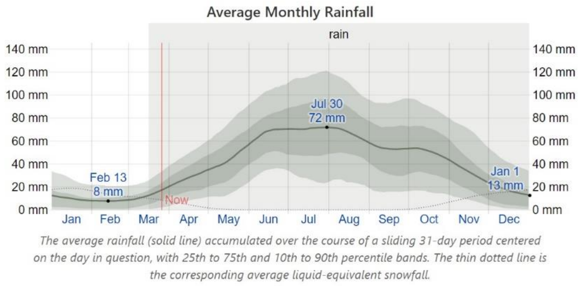
DATA PRODUCER: ICOS

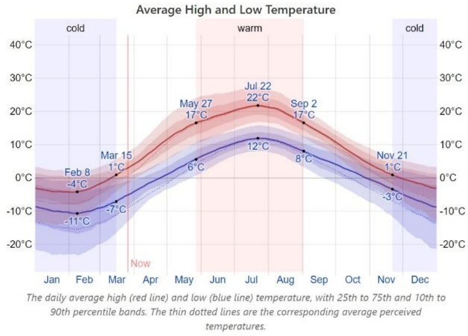
DATASET DATA FREQUENCY UNIT : 30 min

MEASUREMENT METHOD: Cavity RingDown Spectrometer (instrument Id 311)

Figures 44. Surroundings of the station (Eu-interact 2021)

The station is located in the middle of state-owned forests and peatlands, approximately one hour north-east drive from the city of Tampere (Figures 43 and 44).





Figures 45. and 46. Average monthly rainfall and average high and low temperature for Tampere, which is located 80 km from Hyytiala (Weatherspark 2021).

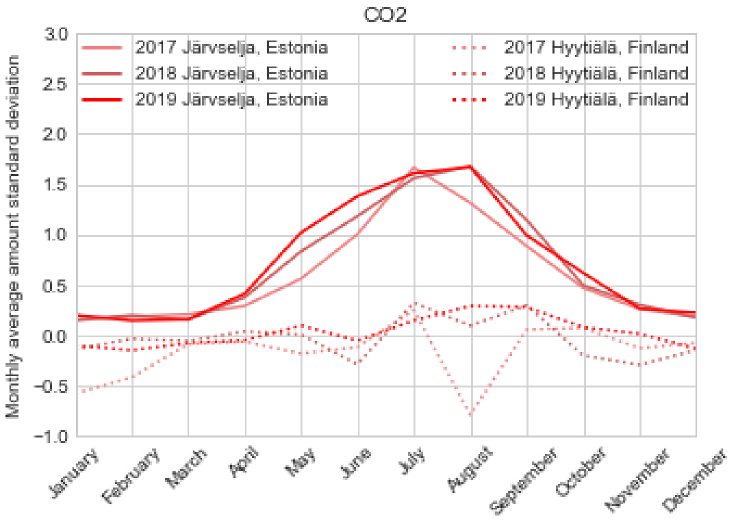


Figure 47. Monthly average on CO2 concentration (ppm)

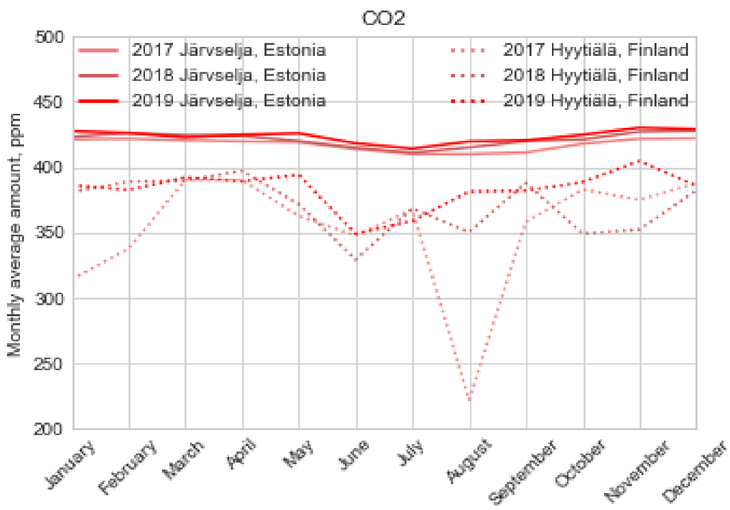


Figure 48. Standard deviation for monthly average of CO2 concentration (ppm)

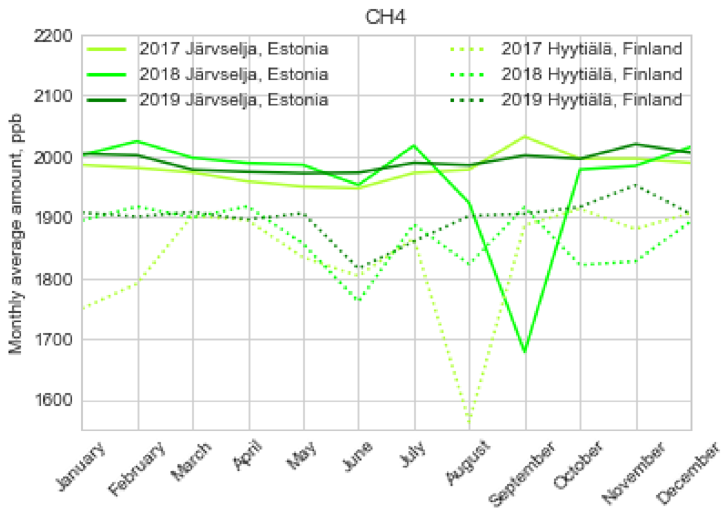


Figure 49. Monthly average of CH4 concentration (in ppb)

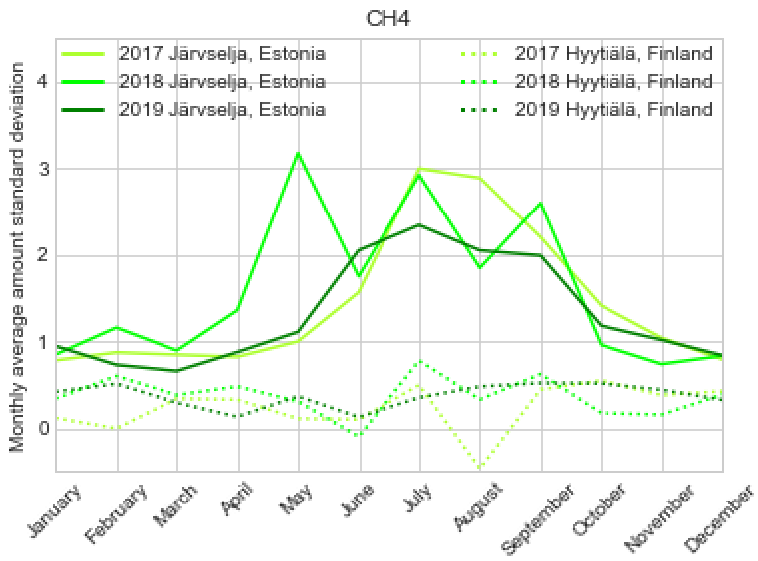


Figure 50. Standard deviation for monthly average of CH4 concentration (in ppb)

Hyytiälä has similar to Järvselja ecosystem of forests with peatland and is located 500 to the north from Järvselja.

The graphs show that the concentration of CO2 and CH4 in Hyytiälä are lower than in Järvselja. (Figures 47 and 49). That can be explained by higher altutude of Hyytiälä (181 m above see level and 46 m above see level in Järvselja).

However, data from Hyytiälä is very diverce and is hard to analyze. The only clear pattern we can see is the rice of consentration of CO2 and CH4 during the time. Also seasonal variation can be interpretated as influence of vegetaton.

Standart deviation (Figures 48 and 50) show dynamic in both Hyytiälä and Järvselja in spring-summer periods due to many bioprocesses related to vegetatinal grow.

3.1.2.2. Norunda, Sweden and Järvselja, Estonia

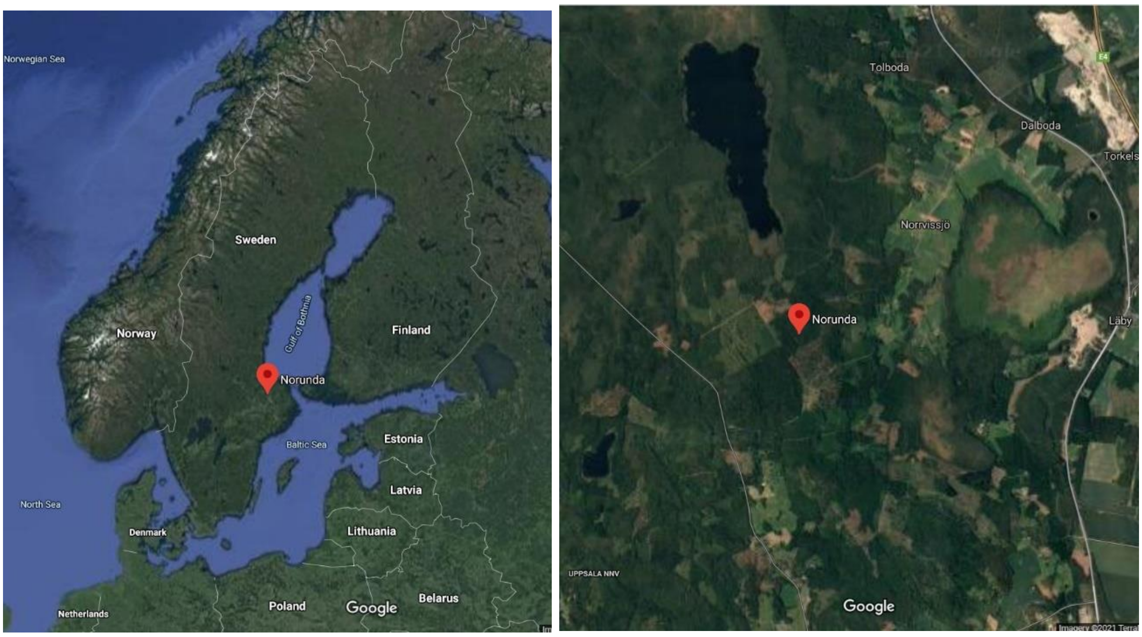


Figure 51. Location of the station on 1 km and 200 km scale (Google maps 2021)

ALTITUDE: 46 m above the sea level

SAMPLING HEIGHTS: 32.0 m

ECOSYSTEM TYPE: boreal forest (ICOS 2021)

DATA PRODUCER: ICOS

DATASET DATA FREQUENCY UNIT : 30 min

MEASUREMENT METHOD: Cavity RingDown Spectrometer (instrument Id 462)

Figures 52. Surroundings of the station (ICOS Sweden 2021)

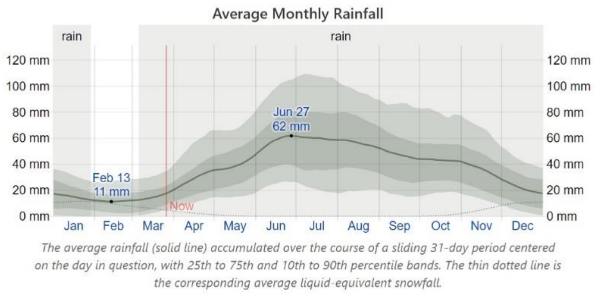
Scientists of the measuring site describe the area surrounding as followed:

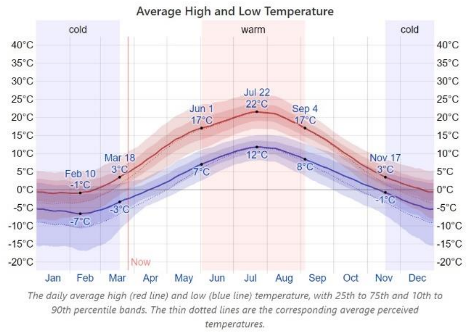
The Norunda research station is located about 30 km north of Uppsala, i.e., in the southern part of the boreal forest zone. (Figures 51 and 52. *)The area is flat with small-scale variations in altitude (up to 10 m).The bedrock is characterised by granite and gneiss (incl. leptite) from the Svecokarelian orogen. The soils are sandy-loamy tills with a high content of stones and blocks, characterized as podzolised dystric regosols, with a thin organic layer on top. The area is rich in organic soils with surface peat cover and fens. Because of the presence of stones and blocks the soil surface is highly uneven. The site is dominated by Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) with a small fraction (15%) of deciduous trees, mainly birch (*Betula sp.*). The shrub layer is dominated by blueberry, cranberry, moss, and flowers.*

The site contains stands of various age and height, but within a 1 km radius, old (110 years) and middle-aged (60-80 years) forest of about 25 m height dominate. The canopy density varies mainly depending on species composition and the Leaf Area Index (LAI) is typically in the range 3-6, but can be as high as 7.

With a mean annual air temperature of 7.1°C and a mean annual precipitation of 556 mm (data period 1991-2020, SMHI station Uppsala Aut) the climate is characterized after Köppen as a Dfb-climate, i.e. humid continental with moderate summers and cold winters. Southwest is the prevailing wind direction in Norunda.

data period 1961-1990: mean annual air temperature 5.6°C, a mean annual precipitation of 544 mm (SMHI station Uppsala) (ICOS Sweden, 2021)





Figures 53. and 54. Average monthly rainfall and average high and low temperature for Uppsala, which is located 30 km from Norunda (Weatherspark 2021).

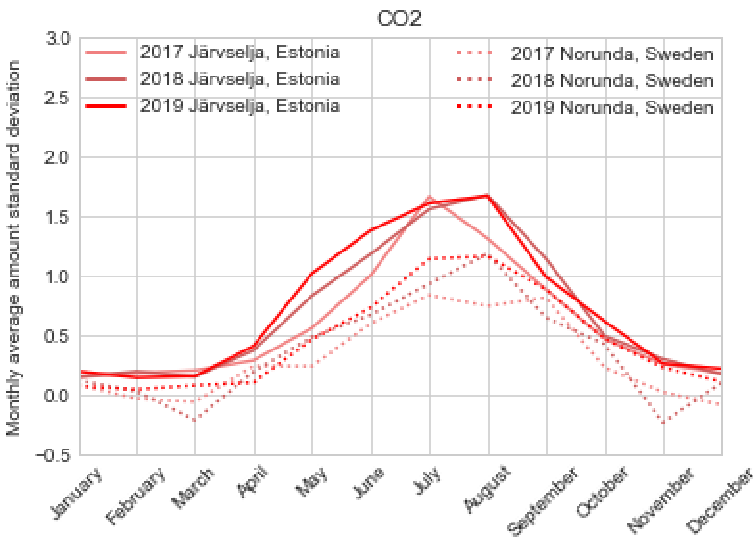


Figure 55. Monthly average on CO2 concentration (ppm)

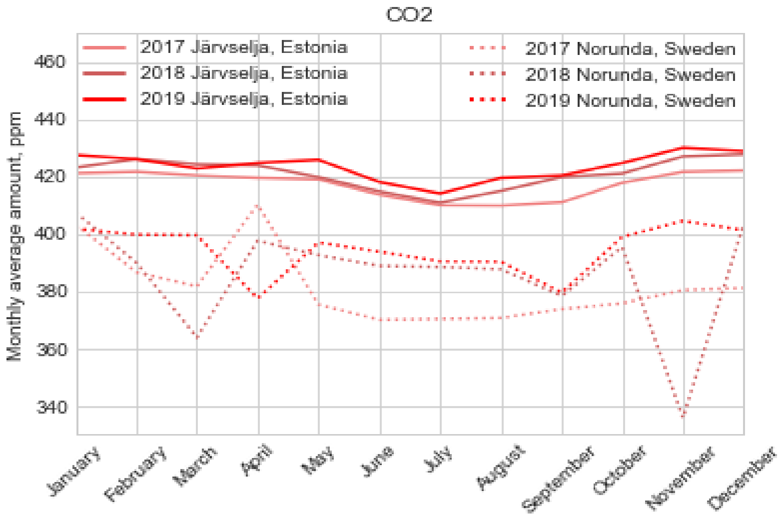


Figure 56. Standard deviation for monthly average of CO2 concentration (ppm)

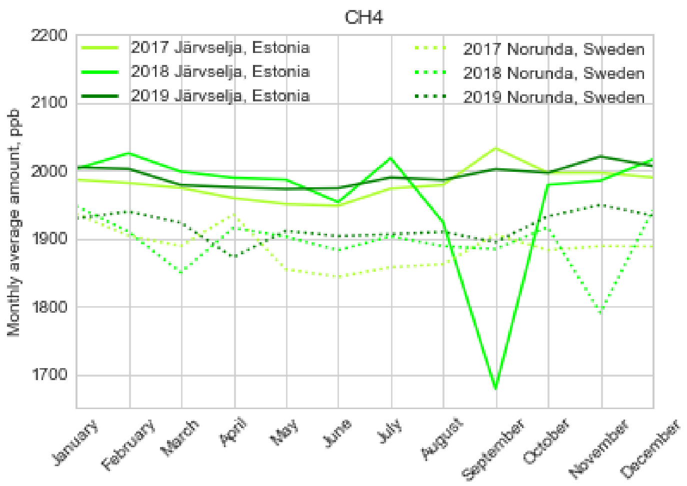


Figure 57. Monthly average of CH4 concentration (in ppb)

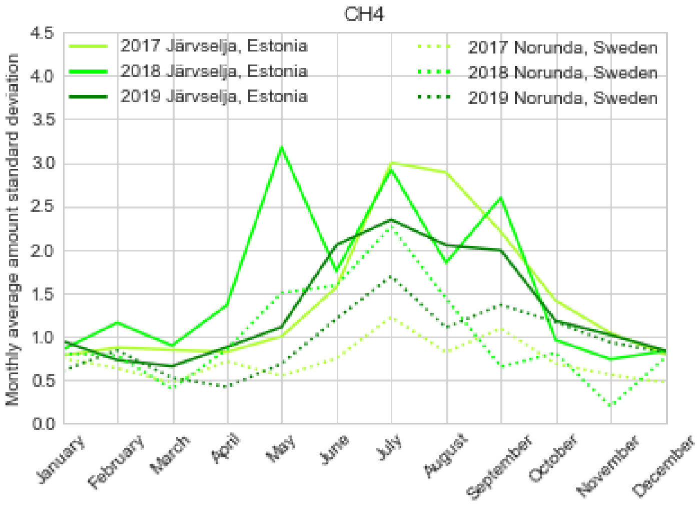


Figure 58. Standard deviation for monthly average of CH4 concentration (in ppb)

Norunda is located on the same altitude as Järvselja (46 m above the see level).

The graphs show that the concentration of CO2 in Norunda are lower than in Järvselja. (Figures 55 and 57). Data from Norunda is very uneven, similar to Hyytiälä. The only clear pattern we can see is the rice of consentration of CO2 and CH4 during the time. Also seasonal variation can be interpretated as influence of vegetaton.

The data for January, February and March was missing, therefore it was replaced by average of the values for the same months in other available years and indicated under the graph (for example at Norunda sight for January, February and March).

Standart deviation (Figures 56 and 58) show dynamic in both Norunda and Järvselja in spring-summer periods due to many bioprocesses related to vegetatinal grow.

3.1.2.3. Sammaltunturi, Finland and Järvselja, Estonia

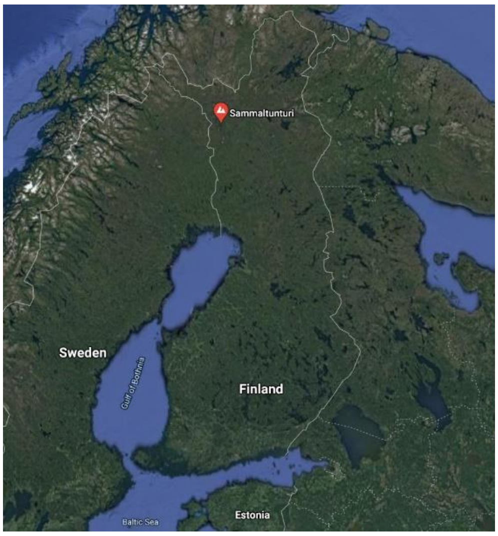


Figure 59. Location of the station on 1 km and 200 km scale (Google maps 2021)

ALTITUDE: 570.00 m above the sea level

SAMPLING HEIGHTS: 5 m

ECOSYSTEM TYPE: boreal forest

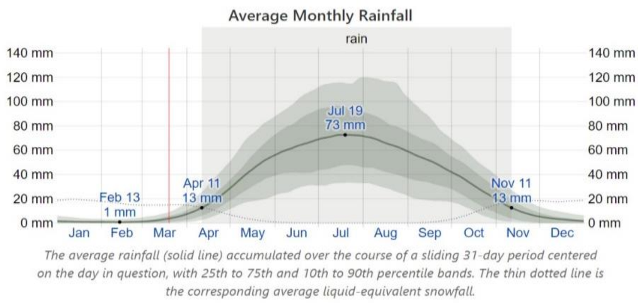
DATA PRODUCER: NOAA

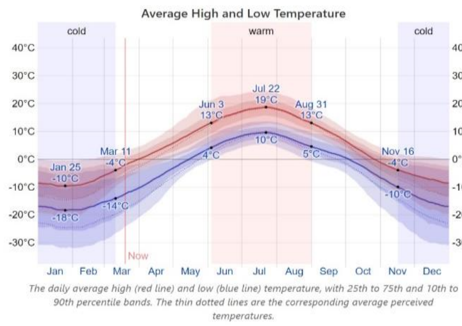
DATASET DATA FREQUENCY UNIT : week

MEASUREMENT METHOD: CO2 dry air mole fractions reported in these files were measured by a nondispersive infrared absorption
analyzer or cavity ring-down spectrometer in air samples collected in glass flasks at NOAA GML Carbon Cycle Cooperative Global Air Sampling
Network sites.

Figures 60. Surroundings of the station (Ilmatieteenlaitos 2021)

As is stated by NOAA, *station is located within the Pallas-Yllästunturi National Park, inside the northern boreal forest zone. The Pallas area is free of large local and regional pollution sources with the nearest town, Muonio with some 2500 inhabitants, being 19 km to the west (Figure 59 ja 60). The second-nearest town, Kittilä, with 6000 inhabitants, is 46 km to the south-east. The main station, Sammaltunturi (67°58'N 24°07'E, 560 m a.s.l.) is on top of a fjeld (a subarctic hill), ca. 300 m above the surrounding area and some 100 m above the tree line. The vegetation on the fjeld top consists mainly of low vascular plants, moss, and lichen. The region is hilly with the highest elevations of 600-800 m within 3-6 km from the station.*





Figures 61. and 62. Average monthly rainfall and average high and low temperature for Sammaltunturi (Weatherspark 2021).

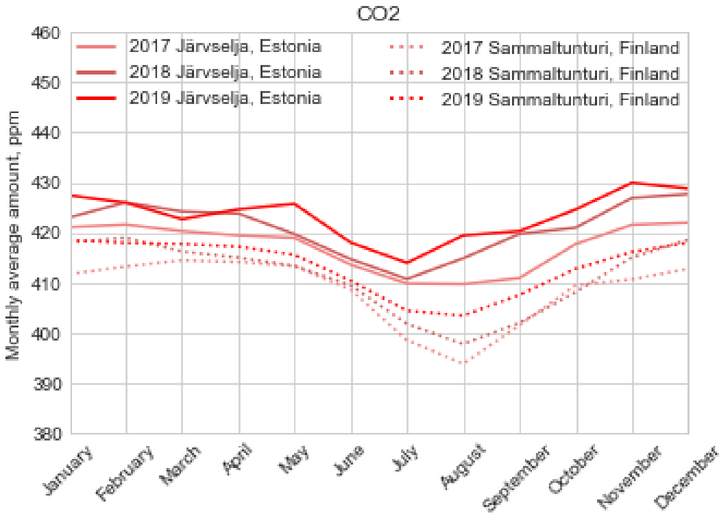


Figure 63. Monthly average of CO2 concentration (in ppm)

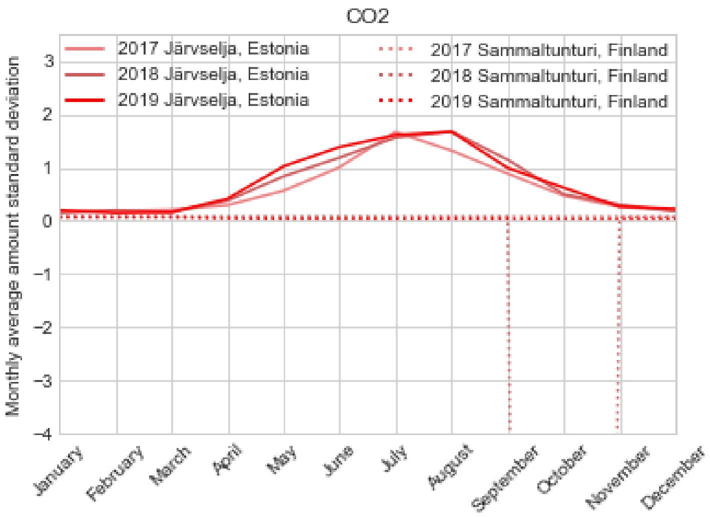


Figure 64. Standard deviation for monthly average of CO2 concentration (ppm)

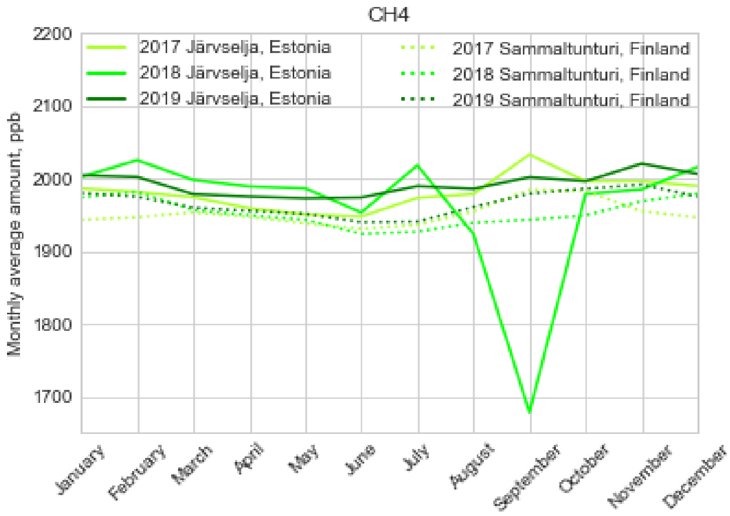


Figure 65. Monthly average of CH4 concentration (in ppb)

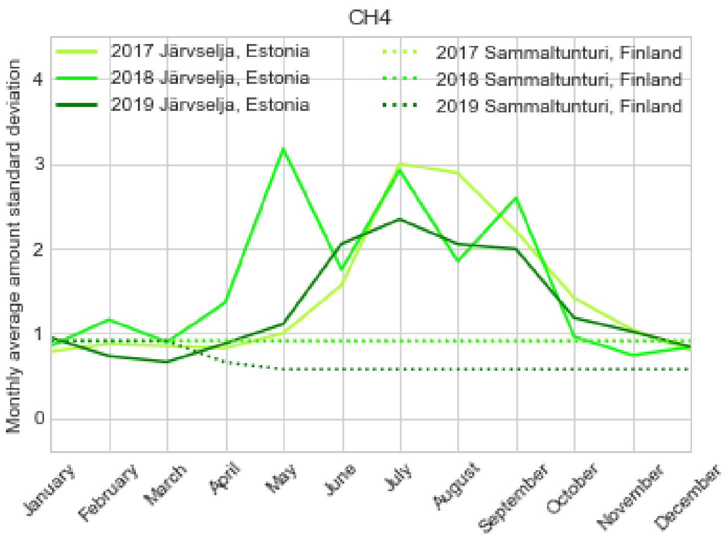


Figure 66. Standard deviation for monthly average of CH4 concentration (in ppb)

The graphs show that the concentration of CO2 in Sammaltunturi is lower than in Järvselja (Figures 63 and 65). That can be explained by higher altutude of Sammaltunturi (565 m above see level and 46 m above see level in Järvselja). The concentration of CH4 in Sammaltunturi and in Järvselja is almost equal, probably due to the same type of ecosystem they share – both are surrounded by boreal forests.

On both CO2 and CH4 graphs we see seasonal influence – there is more CO2 sequestrated by vegetation in summer period and more CH4 extracted during autumn (Figures 63 and 65).

Standart deviation of the data correlates with the ammount of rainfall, first of all because high humidity creates dinamic for many processes (for example vegetational growth, soil respiration), secondly because high humidity makes data more uncertain – molecules of water affect the concentration of gas (Figures 64 and 66).

3.2. Net ecosystem exchange within Järvselja, Estonia

The quantitative measure of the net C exchange between the ecosystem and the atmosphere is named the net ecosystem exchange (NEE) (Chapin et al. 2006 ref Krasnova et al. 2019). NEE is a result of two opposite processes, namely, C uptake from plant photosynthesis and C release from respiration of living organisms. On an ecosystem level, gross primary produ ction (GPP) represents photosynthesis, and ecosystem respiration (RE) in a combination of all C release processes from both autotrophs (vegetation) and heterotrophs (microorganism in the soil).. Both GPP and RE are influenced by number of environmental processes and fa ctor. (Krasnova et al. 2019)
From the point of geobotanical view the forest type around the SMEAR Estonia station can be generally describes as hemi-boreal, as it lies between the temperate and subcritical (boreal) climate zones. (Noe et al. 2015).

In hemiboreal forests the NEE-based carbon sequestration and also GPP is higher than in the northern forests (mostly covered by Norway spruce), but still lower than in more southern regions at lower latitudes in Europe (mixed forest with higher proportion of deciduous trees). (Krasnova et al. 2019) Major factors affecting the seasonal course and amount of ecosystem gross primary production, are seasonal differences in leaf-area index, physiological capacity, temperature, amount of rainfall, and the length of the growing season. (Krasnova et al. 2019)

Ecosystem respiration as the sum of heterotrophic respiration and autotrophic respiration. (Krasnova et al. 2019) Periods of high heterotrophic respiration activity do not always correlate with periods of photosynthetical activity of vegetation. (Falge et al. 2002)

As a result we can see that respirational activity in the end of autumn is higher than gross primary production from photosynthetical activity of vegetation. (Figures 67, 68 and 69)

A research derived from FLUXNET measurements indicate similar contribution of autotrophic respiration to ecosystem carbon metabolism in the temperate and the boreal systems (49–52%). (Krasnova et al. 2019) It is researched that total respiratory costs of assimilated carbon are higher in the boreal systems (85% for boreal systems compared to 74–77% for temperate), indicating a larger contribution of respiration in boreal systems. (Krasnova et al. 2019)

The compare of gross primary production of forests in Estonia, Finland and Sweden correspond to the previous researches of SMEAR stations and confirm that it falls from south latitudes to the north ones.

That may indicate a possible increase of gross primary production due to global climate warming. (Keeling et al., 1996a; Myneni et al., 1997; Hasenauer et al., 1999; Menzel and Fabian, 1999; Randerson et al., 1999; Keyser et al., 2000; Baldocchi et al., 2001 ref Krasnova et al. 2019) indicate an extension of the period favourable for assimilation. Growing season length strongly affects annual net ecosystem productivity, hence, the biosequestration capacity of the forest ecosystem in northern hemisphere is expected to extend. (Falge et al. 2002)

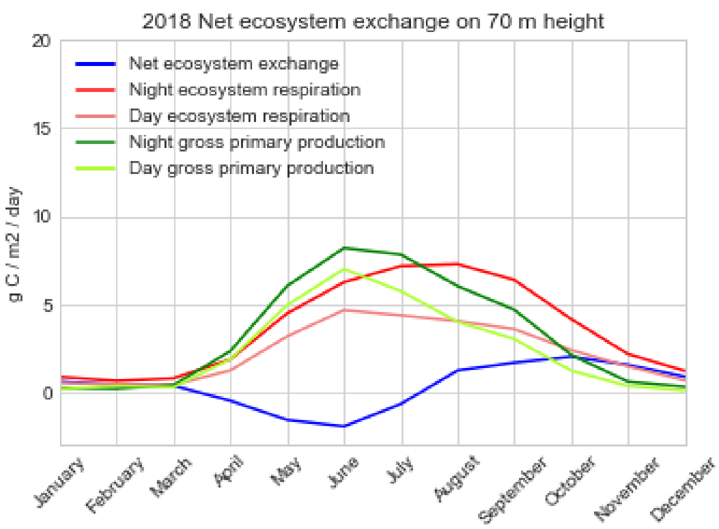


Figure 67. Net ecosystem exchange on 70 m height in Järvselja forest for 2018

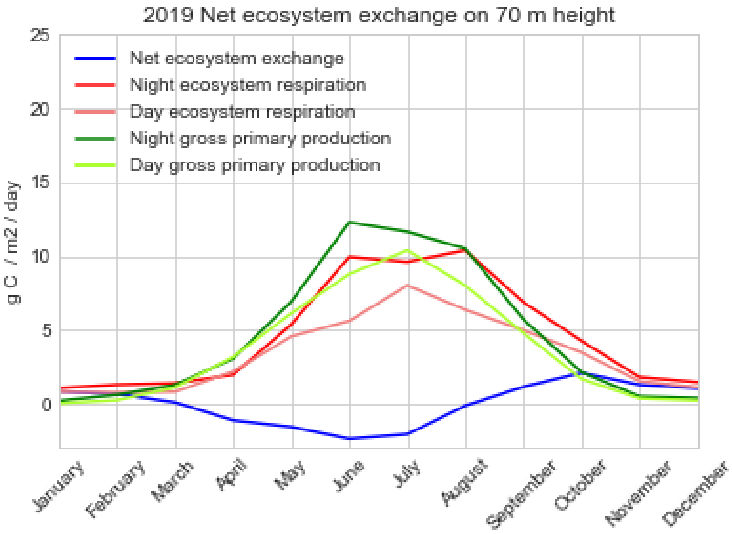


Figure 68. Net ecosystem exchange on 70 m height in Järvselja forest for 2019

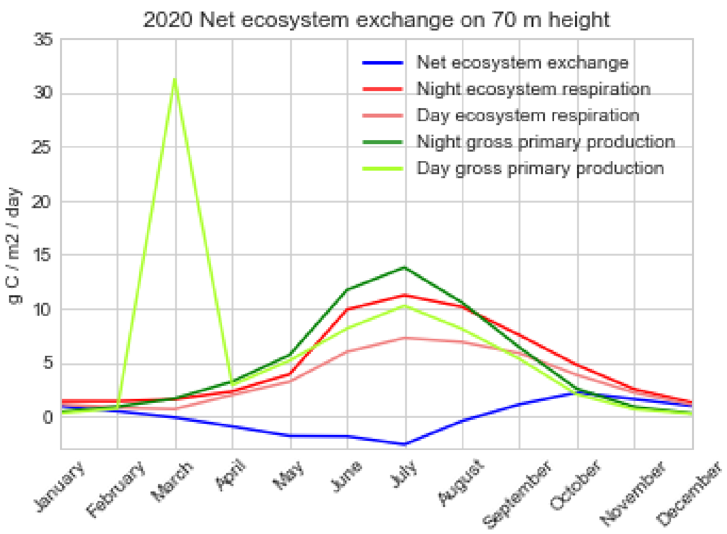


Figure 69. Net ecosystem exchange on 70 m height in Järvselja forest for 2020

Usually the night ecosystem exchange and respiration measurements are made by estimation which derives from daytime measurements. But in case of Järvselja the values are real measurements of values. This means that night time measurements of SMEAR Järvselja represent as accurate data as possible (Figures 67, 68 and 69).

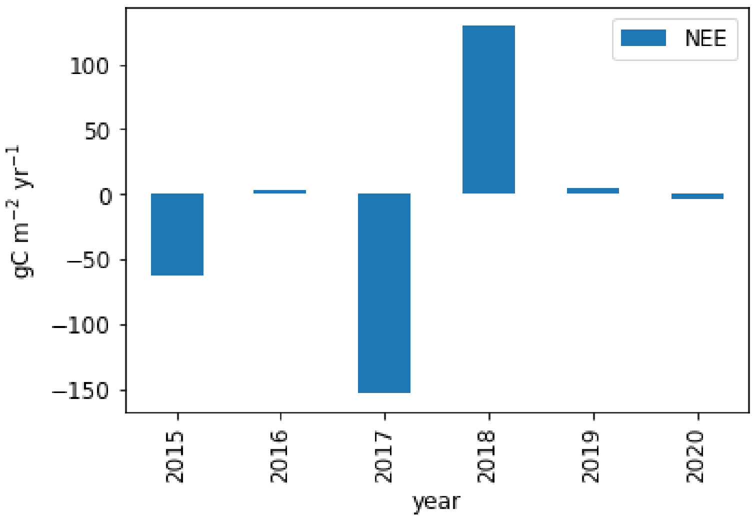


Figure 70. Yearly Gross primary production (GPP) of Järvselja forest

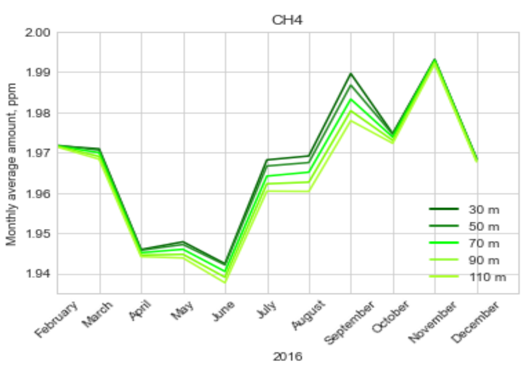
At Figure 70 we can see that Järvselja forest in overall is a carbon sink, but not always. In 2018 it's emissions of carbon and methane were higher that biosequstration. The reason of that was probably the drought which occurred during 2018

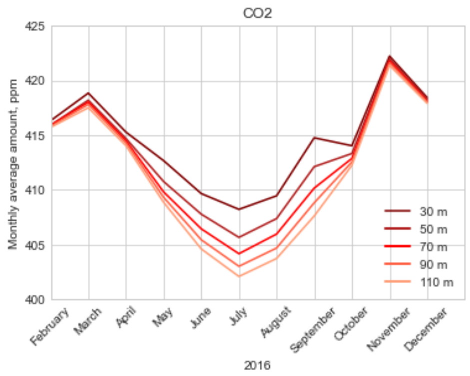
3.3. Factors influencing measurements

3.3.1. Altitude of the measuring site and measuring height

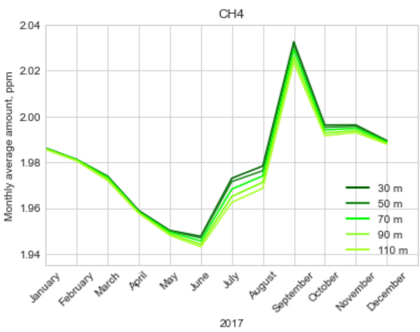
Below are represented graphs with CH4 and CO2 concentration level as well as water vapor and temperature from Järvselja station (Figures 71-76). Samples are taken on different heights: 30m, 50m, 70m, 90m and 110m at the same time.

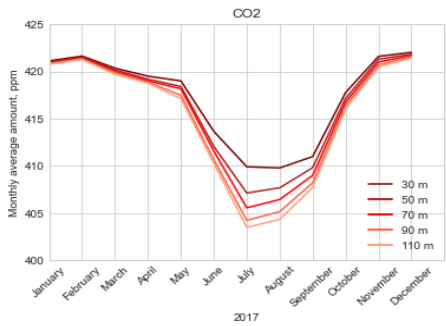
Graphs illustrate a certain negative correlation between the concentration and the height - the lower the height is, the bigger is the concentration. Reason of this are the winds, which rapidly distribute the volatile gasses through the atmosphere. Closer to the ground there is less wind and hence the gases can stay longer and accumulate the concentration. Due to this effect, the height on which the equipment collected samples (sampling height) plays a crucial role on the result and certainly must be taken into account in the analysis.



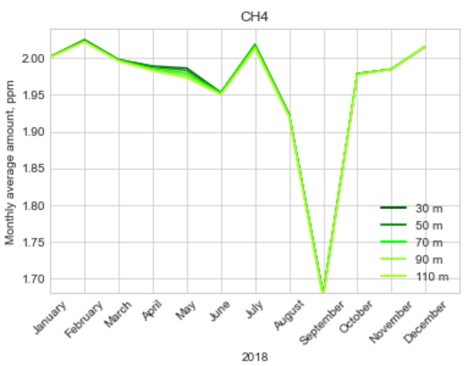


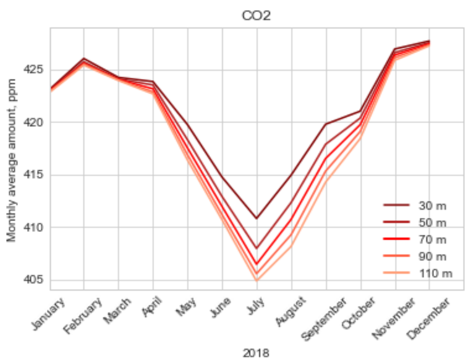
Figures 71. Ja 72. Graphs illustrate a certain negative correlation between the concentration and the height - the lower the height is, the bigger is the concentration.





Figures 73. Ja 74. Graphs illustrate a certain negative correlation between the concentration and the height - the lower the height is, the bigger is the concentration.





Figures 75. And 76. Graphs illustrate a certain negative correlation between the concentration and the height - the lower the height is, the bigger is the concentration.

The same effect takes place also with altitude of the measurement station. Concentration of gases is usually higher if the measuring site is located on low land, not high above the sea level (as for example altitude of SMEAR station in Järvselja is only 46 m above the sea level). Concentration of gases is certainly lower on measurement site, which is located on high altitude (for example Mauna Loa, 3437 m above the sea level), because wind distributes the gases and they are not collected on one place. Altitude must be always taken into account, otherwise a false conclusion can be made – it is a mistake to think that a place with higher concentration of greenhouse gases is more contaminated compared to another if it is located significantly lower than the other one (for example, Estonia will always have higher concentration of greenhouse gases if compared to mountain areas, just because of the difference in the altitude).

3.3.2. Rain fall and temperature

Amount of rainfall and seasonal changes in temperature also play an important role for the biosequestration, as the photosynthetical activity of the vegetation depends on these values. The maximum point of carbon biosequstration correlates with maximum of temperature and rainfall (Figures 45, 47, 53, 55, 61, 63), which for Järvselja is in July. It is likely that the global climate change may increase the capacity of biosequstration (in our climate zone, where the rainfall ammount is usually high) by extencion of the vegetation period. (Keeling et al., 1996a; Myneni et al., 1997; Hasenauer et al., 1999; Menzel and Fabian, 1999; Randerson et al., 1999; Keyser et al., 2000; Baldocchi et al., 2001 ref Krasnova 2019). However, this conclusion may become false in case the rainfall amount falls down.

Temperature and rainfal also influence gross primary production of vegetation. Drought is the main driver what can change forests from carbon sinks to carbom emmiters. That effect took place in 2018, when Estonia suffered from drought and the net ecosystem exchange fell to the point of -130 g of C per square meeter in a year (Figure 70).

3.3.3. Ecosystem

Ecosystems have their own signatures in greenhouse gas concentration measurements. This is easily observable on measurement sites in northern hemisphere, where seasonal dynamic of vegetation takes place. (Figures 47, 55, 63). Usually we can observe that concentration of CO_2 in northern hemisphere is lowering down on time when vegetation is present and the concentration of CO_2 is rising up in cold period when vegetations capacity of biosequestration CO_2 is lowering down.

CH_4 concentrations oppositely usually indicate ecosystems with vegetation. Due to the fact that CH_4 is produced from rotting vegetation, its concentration is relatively high in forest and especially swamp ecosystems. However, northern peatlands represent a crucial ecosystem for regional GHG budgets because they store large amounts of C (Loisel et al., 2014). However, the ratio between decomposition and conservation of the C depends on the vegetation types present, for example, Sphagnum mosses are more resistant to decomposition compared to sedges and other vascular plants and thereby retain more C over time (Rydin & Jeglum, 2006).

The results of this work showed the mean yearly gross primary production of Järvselja forest is 1556 g C / m^2 / year. For an example the yearly gross primary production of Norunda, Sweden is 1691 g C / m^2 / year (ICOS 2021) and Hyytiala, Finland - 959 g C / m^2 / year (ICOS 2021). These results correspond to the previous researches of SMEAR stations and confirm that it falls from south latitudes to the north ones. All of these measuring sites belong to boreal forest ecosystem type with include of wetlands.

4. CONCLUSION AND DISSCUSSION

Aim of this thesis work is to research forest ecosystem's influence on greenhouse gas concentrations and estimate forest ecosystem's capacity to biosequestrate (on an examle of forest in Järvselja).

The research work does prove the hypotetsys that forest ecosystem biosequestrate more CO_2 than they emit. We can see that form a specific pattern which is visible on the graphs from areas with abundant vegetation. The net ecosystem exchange graphs also prove that forest ecosystem is a carbon sink, but also show that this is not always so – some circumstances like drought can make forest a negative carbon sink (emit more than biosequstrate). Also forest type plays a crucial role, as wetlands are source of CH_4 and by that are working against biosequstration.

Another very important factor which must be taken into account during analysis is the altitude of the measurement site - gas concentration in the lowlands will be always higher than on the mountain tops. For the same reasons the measuring height is very important.

Temperature and the amount of rainfall influence vegetational grow and, hence – the biosequestration capacity of the ecosystem.

During this work it was often underlined that ecosystems have very complex processes embedded together and many factors must be taken into account before any wide conclusions are made. As an example – we can see from the graphs that Estonia was one of the highest concentrations of CO_2 and CH_4. However, that does not tell that Järvselja is the greatest emiter of greenhouse gases, because the measurements in Järvselja were taken on a lower height than in other measurement sites, which already states that concentrations must be higher. Areas with forests also show a more high and dynamic concentration of CH_4 that mountain or polar deserts. The reason of that is vegetational decompostion, which may occur only in areas with vegetation.

It can be concluded that CH_4 emittions from forest and wetland ecosystems is an accompanying to biosequstration process. Although it works oppositly to biosequstration, it can not be separated from biosequestration.

This information may be used in “Land Use, Land Use Change and Forestry” sector for better planning, however the advantages of wetlands (such as ecological value and water storage) must not be forgotten in the process of decision making.

According to this research work the concentration of CO2 is rising with nearly the same speed of 0.5% - 1% ppm per year. Conclusion is that greenhuse gas concentration rise and global warming problems can not be solved localy. Results of the analysis show that concentration is rising all over the world (the most south measurement site included in this research is South pole 90.0000° S, 45.0000° E, the most north - Sammaltunturi, Finland 67.9667° N, 24.1167° E) regardless of the local policy of land use. Atmosphere is a shared value and influencing it may be possible only on a global level.

The compare of gross primary production of forests in Estonia, Finland and Sweden correspond to the previous researches of SMEAR stations and confirm that it falls from south latitudes to the north ones. It is likely that the global climate change may increase the capacity of biosequstration (in our climate zone, where the rainfall ammount is usually high) by extencion of the vegetation period. (Keeling et al., 1996a; Myneni et al., 1997; Hasenauer et al., 1999; Menzel and Fabian, 1999; Randerson et al., 1999; Keyser et al., 2000; Baldocchi et al., 2001 ref Krasnova 2019). Although, that can be true only if the rainfall does not decrease, as drought is the main driving factor for forests to become greenhouse gas emmiters instead of carbon sinks. Predicted changes in climate, including rising temperatures, changes in the amount, intensity, and seasonal distribution of precipitation could affect the hydrology in northern peatlands and by that increase CH4 production (FAO 2008). It is suggested that climate change reduces the capacity of northern peatlands to absorb atmospheric carbon dioxide (Wu & Roulet 2014)

Issue which this work also highlightens is the need and ability to utilise the information collected on measuring stations worldwide. This is a developing field, which is still in a search of the global standard. Countries like Estonia are only making their way to join the world leader groups for environmental data producing. However, this research by it’s comparison of SMEAR Järvselja’s data with data of other measurement stations show that Estonia has a good potential to become a member in environmental data science teams (for example ICOS). Estonia has well developed it-sector and becoming a high-quality environmental data source would strengthen this position.

Data science is a relatively fresh field of study, but it is rapidly developing. Nowadays there are plurality of instruments for data analytics and environmental sciences should take them into account. Measurement stations which collect metheorological and ecosystem information during tens of years are offering huge possibilities for the accurate longterm researches and dessision making.

SUMMARY

Aim of this thesis work is to research forest ecosystem’s influence on greenhouse gas concentrations and estimate forest ecosystem’s capacity to biosequestrate (on an examle of forest in Järvselja). For this the greenhouse gas concentration measurment data from different measuring sites (Järvselja, Estonia; Mauna Loa, United States; Cape point, South Africa; South Pole, Antarctica; Hyytiälä, Finland; Norunda, Sweden; Sammaltunturi, Finland) was compared to see the difference between areas with abundant vegetation and scarse vegetation. By data science methods, Python programming language, the measurement data was visualized and analysed.

The results of the work give the following answers on the research questions:

1. What is influencing greenhouse gas concentrations measurements?

The most important factor is the height from which the measurements were taken, as well as the altitude of the place where the measurement site is located. The lower to the ground, the higher the concentrations will be. Hence, locations 46 m above the sea level have higher concentrations of greenhouse gases if compared to the mountain areas or areas which are open to strong winds. Of course there are many other factors which directly influence the greenhouse gas concentrations, like population size, close location to the city or wetland. But in scale of this work it is not possible to distinguish these influences. However, the even rise of CO2 concentration all over the world with similar speed indicates that this may be useless to research the atmosphere on local points.

2. What is influencing biosequestration?

Main driving factors of biosequestration are temperature and ammount of rainfall, as they influence the photosynthetical activity of the vegetation. In periods of drought or in winters biosequstration capacity lowers down. In places without vegetation graphs of CO2 concentration do not show a specific for the carbon sink pattern. The more north is the location of the forest ecosystem, the lower is it’s net ecosystem exchange, as low temperatures and short vegetation lowers down the biosequstration capacity more than the respirational activity.

3. Are there any differences in greenhouse gas concentrations in areas with different ecosystems?

Results showed that in areas with abundant vegetation these is a clear patern, which represe nts the carbon sink by rapid drop down of CO_2 concentration in the atmosphere in vegetati on grow season. Carbon sink on the graphs correlate with local ammount of rainfall and te mperature, which also indicates that the reason of this is vegetation. For examle, the bigest carbon sink in Järvselja, as well as highest temperature and rainfall, is in July.
On the other hand vegetation is a reason for CH_4 emmitions (rottening processes of organic matter). The more vegetation – the higher is CH_4 concentration, especially that is true to fo rest and wetland ecosystems.

4. Are the greenhouse gas concentrations rising in Estonia with the same speed as in other parts of the world?

According to results of this work, the CO_2 concentration is ricing from South pole to Finnish tundra with nearly the same speed (0.5% - 1% per year). The mean yearly concentration of CO_2 in Estonia (Järvselja) is 416 ppm (https://www.CO2.earth/daily-CO2), what corresponds to the global gerenal number. CO_2 concentrat in Estonia (Järvselja) rises by 0.7% of ppm per year. That means that in Estonia (Järvselja) the concentration of CO_2 is rising slower than generally in the world (0.94%) (CO2earth 2021).

5. Is data of SMEAR station at Järvselja correlating with data of other stations?

Although equipment is not sufficiently enough calibrated on SMEAR Järvselja station, the results made on base of it's measurements correspond to the world recognised ones (for example NOAA, ICOS,).

There are some "strange" measurement values appearing in the data, but not more often than in other datasets.

6. Is forest biosequstration capacity covering it's emissions (on an examle of forest in Järvselja)?

The research work does prove the hypothesis that forest ecosystem biosequestrate more CO2 than they emit. We can see that form a specific pattern which is visible on the graphs from areas with abundant vegetation. The net ecosystem exchange graphs also prove that Järvselja's forest ecosystem is a carbon sink, but also show that this is not always so – some circumstances like drought can make forest a negative carbon sink (emit more than biosequstrate). Also forest type plays a crucial role, as wetlands are source of CH4 and by that are working against biosequstration.

It can be concluded that CH4 emittions from forest and wetland ecosystems is an accompanying to biosequstration process. Although it works oppositly to biosequstration, it can not be separated from biosequestration.

ÜLDKOKKUVÕTE

Kasvuhoonegaaside biosekvestratsioon metsaökosüsteemides Järvselja SMEAR jaama andmete põhjal

Selle lõputöö eesmärk on uurida metsaökosüsteemi mõju kasvuhoonegaaside kontsentratsioonidele ja hinnata metsaökosüsteemi biosekvistratsiooni võimalus (Järvselja metsa näitel). Selle jaoks võrreldi kasvuhoonegaaside kontsentratsiooni mõõtmise andmeid erinevatest mõõtmiskohtadest (Järvselja, Eesti; Mauna Loa, Ameerika Ühendriigid; Cape Point, Lõuna-Aafrika Vabariik; Lõunapoolus, Antarktika; Hyytiälä, Soome; Norunda, Rootsi; Sammaltunturi, Soome). Mõõteandmeid analüüsiti ja visualiseeriti andmeteaduslike meetodite ja Pythoni programmeerimiskeele abil.

Töö tulemused annavad uurimisküsimustele järgmised vastused:

1. Mis mõjutab kasvuhoonegaaside kontsentratsiooni mõõtmist?

Kõige olulisem tegur on kõrgus, kust mõõtmised tehti, samuti mõõtejaama paiknemise kõrgus ja reljeef. Mida madalam on ala, seda kõrgemad on kontsentratsioonid. Seega on 46 m kõrgusel merepinnast kasvuhoonegaaside kontsentratsioon alati kõrgem kui mägipiirkondades või tugevatele tuultele avatud piirkondades. Muidugi on palju muid tegureid, mis otseselt mõjutavad kasvuhoonegaaside kontsentratsiooni, näiteks elanikkonna suurus, linna või märgalaga lähedane asukoht. Kuid selle töö mastaabis pole võimalik neid mõjutusi eristada. CO2 kontsentratsiooni ühtlane tõus kogu maailmas näitab, et atmosfääri uurimiseks kohalikest punktidest võib olla asjatu.

2. Mis mõjutab biotakistust?

Biosekvestreerimise peamisteks teguriteks on temperatuur ja sademete hulk, kuna need mõjutavad taimestiku fotosünteetilist aktiivsust. Põuaperioodidel või talvedel väheneb biosekvistratsiooni võime. Taimestikuta kohtades ei näita süsinikdioksiidi kontsentratsiooni graafikud süsiniku valamu mustri spetsiifilisi näitajaid. Mida põhjapoolsem on metsaökosüsteemi paiknemine, seda madalam on selle ökosüsteemi netovahetus, kuna madal temperatuur ja lühike kasvuperiood langetavad biosekvistratsiooni võimsust vähem kui hingamisaktiivsus.

3. Kas kasvuhoonegaaside kontsentratsioonides on erinevates ökosüsteemides erinevusi?

Tulemused näitasid, et rikkaliku taimestikuga aladel on olemas selge muster, mis esindab süsiniku neeldumist taimestiku kasvuperioodil atmosfääris sisalduva CO2 kontsentratsiooni kiire languse tõttu. Graafikute süsiniku valamu on korrelatsioonis kohaliku sademete hulga ja temperatuuriga, mis näitab ka, et selle põhjuseks on taimestik. Näiteks Järvselja suurim süsiniku valamu ning kõrgeim temperatuur ja vihmasadu toimuvad juulis.

Teisest küljest taimestik põhjustab CH4 ekskretsiooni (orgaanilise aine mädanemisprotsesside pärast). Mida rohkem taimestikku - seda suurem on CH4 kontsentratsioon, eriti kui tegemist on metsa- ja märgalade ökosüsteemide kohtadega.

4. Kas kasvuhoonegaaside kontsentratsioon tõuseb Eestis sama kiirusega kui mujal maailmas?

Selle töö tulemustest selgub et süsinikdioksiidi kontsentratsioon tõuseb Lõunapoolusest Soome tundrani peaaegu sama kiirusega 0,5–1% aastas, mis vastab teistele infoallikatele (https://www.CO2.earth/daily-CO2). Keskmine aastane CO2 kontsentratsioon Eestis (Järvselja) on 416 ppm (https://www.CO2.earth/daily-CO2), mis vastab teistele infoallikatele. CO2 kontsentratsioon Eestis (Järvselja) tõuseb 0,7% ppm aastas. See tähendab, et Eestis (Järvseljal) tõuseb CO2 kontsentratsioon aeglasemalt kui maailmas üldiselt (0,94%) (https://www.CO2.earth/daily-CO2)

5. Kas SMEAR Järvselj jaama andmed on korrelatsioonis teiste maailma jaamade andmetega?

Ehkki seadmed ei ole SMEAR Järvselja jaamas piisavalt kalibreeritud, vastavad selle mõõtmiste põhjal tehtud tulemused maailmas tunnustatud tulemustele (näiteks NOAA, ICOS jne). Andmetes on mõned „imelikud” mõõteväärtused, kuid mitte sagedamini kui teistes andmekogumites.

6. Kas metsa ökosüsteemi biosekvistratsiooni võime katab selle heitkogused (Järvselja metsa näitel)?

Uurimistöö tõestab hüpoteesi, et metsaökosüsteemid biosekvistreerivad rohkem kui nad eraldavad. Ökosüsteemi netovahetusgraafikud tõestavad, et Järvselja metsaökosüsteem on süsiniku neeldaja, kuid näitavad ka, et see pole alati nii - mõned asjaolud, nagu põud, võivad muuta metsa biosekvistratsiooni võime negatiivseks. Samuti on metsatüübil ülioluline roll, kuna märgalad on metaani allikad ja selle pärast töötavad biosekvistratsiooni vastu.

Võib järeldada, et metsa- ja märgalade ökosüsteemidest pärinevad CH4 heitkogused kaasnevad biosekvistratsiooni protsessile. Ehkki see toimib vastupidiselt biosekvistratsioonile, pole võimalik seda eraldada biosekvistratsioonist.

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